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AN EXPERIMENTAL ELECTRON MICROSCOPE FOR 400 KILOVOLTS

by A. C. van DORSTEN, W. J. OOSTERKAMP and J. B. le POOLE. 621.385.833

When the acceleration voltage of an electron microscope is raised its resolving power is improved, theoretically. A more important advantage, however, is that at high voltages thick specimens can be studied, which at lower voltages would not give a satisfactory image, due, *i.a.*, to the excessive scattering of the electrons. In this article an experimental electron microscope is described which has been built in the Philips Laboratory in Eindhoven. It works with voltages up to 400 kilovolts. The instrument contains an objective aperture, adjustable from the outside, with four different openings, which provide the means for obtaining the best possible contrast in the image for any specimen. It has been found, for instance, that in a special case of yeast cells, whose internal structure is not sharply defined at 100 kV, the fine structures can be clearly observed when 350 kV is applied. Finally measures are discussed for the protection of the observer against the X-radiation excited in the microscope.

Advantages of an electron microscope with high acceleration voltage

Most electron microscopes used until now work with an electron beam of a energy of 50 to 150 kV. In the Philips Laboratory in Eindhoven an electron microscope has been built for use with electron beams having an energy of 400 kV. Before describing this instrument we shall discuss the advantages connected with the use of a high acceleration voltage.

We shall first devote our attention to the resolving power. When the acceleration voltage is increased the resolving power is improved, at least theoretically, *i.e.* the distance between two details which can just be separately distinguished is reduced. This is explained as follows. It is known that moving electrons are to be regarded as having the nature of a wave, the wavelength λ being given by the equation

$$\lambda = \frac{12.3}{\sqrt{V}}\ \text{Å}, \quad \ldots \ldots \quad (1)$$

where V represents the acceleration voltage in volts. From this it may be seen that upon increasing the voltage the wavelength of the electrons is reduced, which means an increase in the resolving power [1]). In order to examine this more closely it must be noted that at the high voltages now under consideration formula (1) is no longer exactly valid. A correction must be introduced according to the relativity theory. It then becomes

$$\lambda = \frac{12.3}{\sqrt{V_c}}\ \text{Å}, \quad \ldots \ldots \ldots \quad (2)$$

where

$$V_c = V(1 + 0.98 \cdot 10^{-6}\, V).$$

We shall call V_c the corrected voltage. This value must also take the place of V in the formula for the power of a magnetic electron lens, which formula is derived in the article referred to in footnote [1]). When the acceleration voltage of the microscope amounts to 400 kV, the corrected voltage is 560 kV. It may be seen from formula (2) that as the accelleration voltage is increased by the relativity correction so the wavelength is reduced more rapidly than would be expected from formula (1).

The limiting value which can be reached for the resolving power of an electron microscope depends not only upon λ, but also on the magnitude of certain inevitable aberrations, especially those due to diffraction and spherical aberration. It has been found that the highest resolving power is obtained when there is a certain ratio between the diffraction error and the spherical aberration. On that

[1]) See for example J. B. Le Poole. A new Electron Microscope with Continuously Variable Magnification, Philips Techn. Rev. 9, 33-45, 1947.

basis the following relation has been derived for the resolving power:

$$d_{\min} = 0.56 \sqrt[4]{\lambda^3 C} \,. \quad . \quad . \quad . \quad (3)$$

It can further be shown that the smallest attainable value of the quantity C occurring in formula (3) is proportional to the dimensions of the lens, which in turn are proportional to the square root of the corrected voltage. If the corrected voltage is chosen n times as large, C thus becomes $\sqrt{n}$ times as small. The resolving power is then improved and

$$d_{\min, n} = d_{\min} \sqrt[4]{\sqrt{n}/\sqrt{n^3}} = d_{\min} \sqrt[4]{1/n}\,.$$

When the acceleration voltage rises from 150 to 400 kV and thus the corrected voltage is increased from 165 to 560 kV, an improvement in the resolving power by a factor 0.73 can therefore be expected. This means that the smallest observable distance is now more than 25% smaller.

This must indeed be considered as a not unimportant improvement in the quality of the image. But such an improvement alone does not justify the construction of the expensive apparatus which is necessary when such a high acceleration voltage is to be used in electron microscopes. Before we mention the second advantage of a high acceleration voltage we shall first consider somewhat more closely the formation of the image in an electron microscope.

For the observation of a given detail of an object it is not enough that its dimensions should be larger than those corresponding to the resolving power of the microscope. There must also be sufficient contrast in the image studied. The eye cannot distinguish sharply between two parts of the image whose brightness differs by less than a certain amount. The percentage depends upon the observer, the illumination and the nature of the object.

How is contrast brought about in an electron microscope? The scattering of the electrons in the specimen is almost exclusively responsible for the contrast. The scattering is proportional to the mass through which the beam passes, so that the heavier the part of the specimen through which they have passed the more the electrons are scattered. The electrons which are scattered beyond a critical angle strike the objective aperture and do not contribute to the excitation of light on the fluorescent screen. The remaining electrons passing through the specimen and the objective are focussed to an image by the magnetic field of that lens. The diagram of *fig. 1* illustrates this.

Let us suppose that it is desired to examine with an electron microscope, working with a low acceleration voltage, a thick specimen, for instance a microtome section, yeast cells or a chromosome specimen. The specimen will then scatter the electrons so much that nearly all of them will fall on the objective aperture. The image is consequently almost completely black, so that no internal structures can be seen.

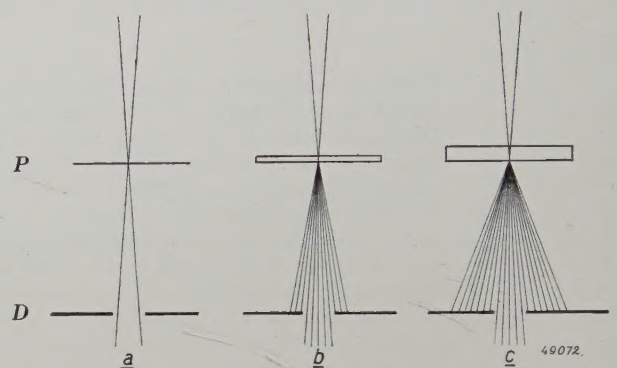

Fig. 1. The scattering of the electrons by objects of different thickness. In *a*, *b* and *c* rays are drawn which pass respectively through a very thin, a medium and a thick specimen *P*. *D* represents the objective aperture which captures part of the electrons in each case. In thick parts of the specimen the scattering is so great that only a small number of the rays reach the image. As a result the part of the image corresponding to a thick part of the specimen will be much "darker" than the rest.

By careful examination of the phenomena which occur when electrons pass through a thick object, one discovers yet another disturbing effect, namely so-called spatial scattering in the object itself. By this is meant the phenomenon that electrons are again deflected from their paths after having passed certain details in the specimen. Consequently there is finally hardly any relation between the direction in which they left the specimen and the spot whence they came. This, of course, has an unfavourable effect upon the resolving power.

Now it might be supposed that better results would be obtained with thick specimens by using a larger objective aperture. As to the first effect mentioned some improvement can indeed be expected, but in any case the error caused by spatial scattering cannot be reduced that way. The only possibility is to use a higher acceleration voltage. When the energy of the electrons is increased the average angle of scattering will decrease quite rapidly and therefore the spatial scattering will at the same time also decrease rapidly. Moreover,

more electrons will be able to pass through the aperture and reach the final screen.

The second and most important advantage of a high acceleration voltage is, therefore, that thick specimens can be studied which would not give a satisfactory image at a low voltage.

It must not be concluded from this that it would be desirable to examine all specimens with electron rays of high energy. From the fact just mentioned, that when the acceleration voltage is increased the mean angle of scattering decreases quite rapidly, it follows of course that the contrast becomes smaller. When a thin specimen gives an image with sufficient contrast at a low acceleration voltage, the contrast will be seen to decrease when a higher acceleration voltage is used. This loss in contrast can be eliminated, however, for the greater part by choosing a smaller objective aperture, but as a rule the quality of the image will nevertheless be found to depreciate. From this it follows that a high voltage is only justified for those specimens for which, owing to their thickness, good results cannot be obtained at a lower voltage.

A third advantage of the use of an electron beam of high energy is the decrease in chromatic aberration. This aberration is caused by fluctuations in the velocity of the electrons. There are different causes of these fluctuations, of which we may mention: uncontrollable variations of the acceleration voltage, and in the case of thick specimens charges of the velocity as a result of non-elastic scattering of the electrons within the specimen. The faster the electrons the less energy they will give off to the specimen. Since chromatic aberration is proportional to the percentage of energy loss, by using electrons with a higher energy a decrease in the effect of chromatic aberration may be expected. Finally it may be mentioned that when a higher acceleration voltage is applied the heating of the specimen is less at the same current density, and the amount of ionization with the specimen, which may be found objectionable in some cases, is reduced at higher voltages.

Description of the instruments

The electron microscope can be divided into three parts: the generator for high d.c. voltage, the acceleration tube and the microscope proper, *i.e.* the tube with the lenses, the fluorescent screen and various auxiliary apparatus. A brief description of each of these parts follows.

The generator for high D.C. voltage

The apparatus for the production of the high voltage is built on the same principles as those employed in the installations which Philips have designed in the last ten years for various institutes for X-ray therapy and nuclear physics. Since this has already been described in detail in earlier numbers of this periodical [2]), a short description will suffice here.

The d.c. voltage is produced by a three-stage cascade generator with a circuit based on the principle of Greinacher and brought to practical realization by Cockcroft and Walton in Cambridge and by Bouwers in Eindhoven.

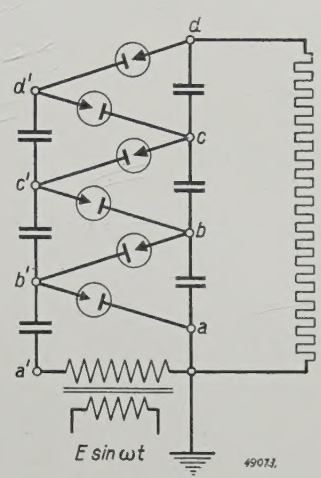

Fig. 2. The circuit of a cascade generator having six valves, which furnishes the no-load voltage $6E$ at d when the amplitude of the a.c. voltage given by the transformer is E. In the circuits ab', $b'b$, etc. are the six valves for 150 kV negative anode voltage.

The principle of this circuit is shown in *fig. 2.* If the amplitude of the a.c. voltage furnished by the transformer is E at d, the d.c. voltage is 6 E. Since in the installation described here the transformer has a peak voltage of 75 kV, the non-loaded generator can produce a d.c. voltage of 450 kV.

For the rectifier valves needed in such generators, in previous cases Philips usually employed mercury vapour valves. Since these are provided with oxide cathodes they have the advantage of a low filament power (8-14 watts). It was not considered advisable, however, to use them in this installation, because these valves have an ignition voltage which is sometimes low, but which may also be of the order of several kilovolts, and since for the electron microscope the voltage on each valve must be constant to within a few tenths per thousand, *i.e.* in this case to within 50 to 100 volts, it was feared that the variable ignition voltage might have an unfavourable effect on the stability of the voltage. Vacuum rectifier valves were therefore used. At the high valve voltage these cannot, it is true, be provided with oxide cathodes [3]), but since the total direct current and thus also the

[2]) Philips Techn. Rev. 1, 6-10, 1936; 2, 161-164, 1937.
[3]) Philips Techn. Rev. 8, 199-205, 1946 (No. 7).

current through the valves is small, it was found possible to use tungsten cathodes with a filament power of about 20 watts.

A high-frequency current is used to feed the filament of the valves [2]). This has the advantage that the current source can be kept at earth potential. This heating current is furnished by a generator with a power of 200 watts and a frequency of 500 000 c/s.

In *fig. 3* the electron microscope is shown with its high voltage installation (except the transformer). For further particulars about this installation, which in certain respects differs from previous types, reference is made to the text under the illustration.

The acceleration tube

The experience gained in the Philips Laboratories in the designing of X-ray installations for high voltages has been turned to account in the construction of the acceleration tube.

An X-ray tube for a million volts has been described in detail in this periodical [4]). This tube consists of three units connected in series. Each has an intermediate partition which is kept at a certain fixed potential, so that the voltage is divided into six equal stages. The electrons emitted by the tungsten cathode are accelerated between the cathode and anode of the first tube and shot into the hollow anode, then flying with a constant velocity through that narrow connection to the second tube, where they are accelerated a second time between cathode and anode, and again accelerated between cathode and anode of the third tube. At

[4]) J. H. van der Tuuk, A Million Volt X-ray Tube, Philips Techn. Rev. 4, 153-161, 1939.

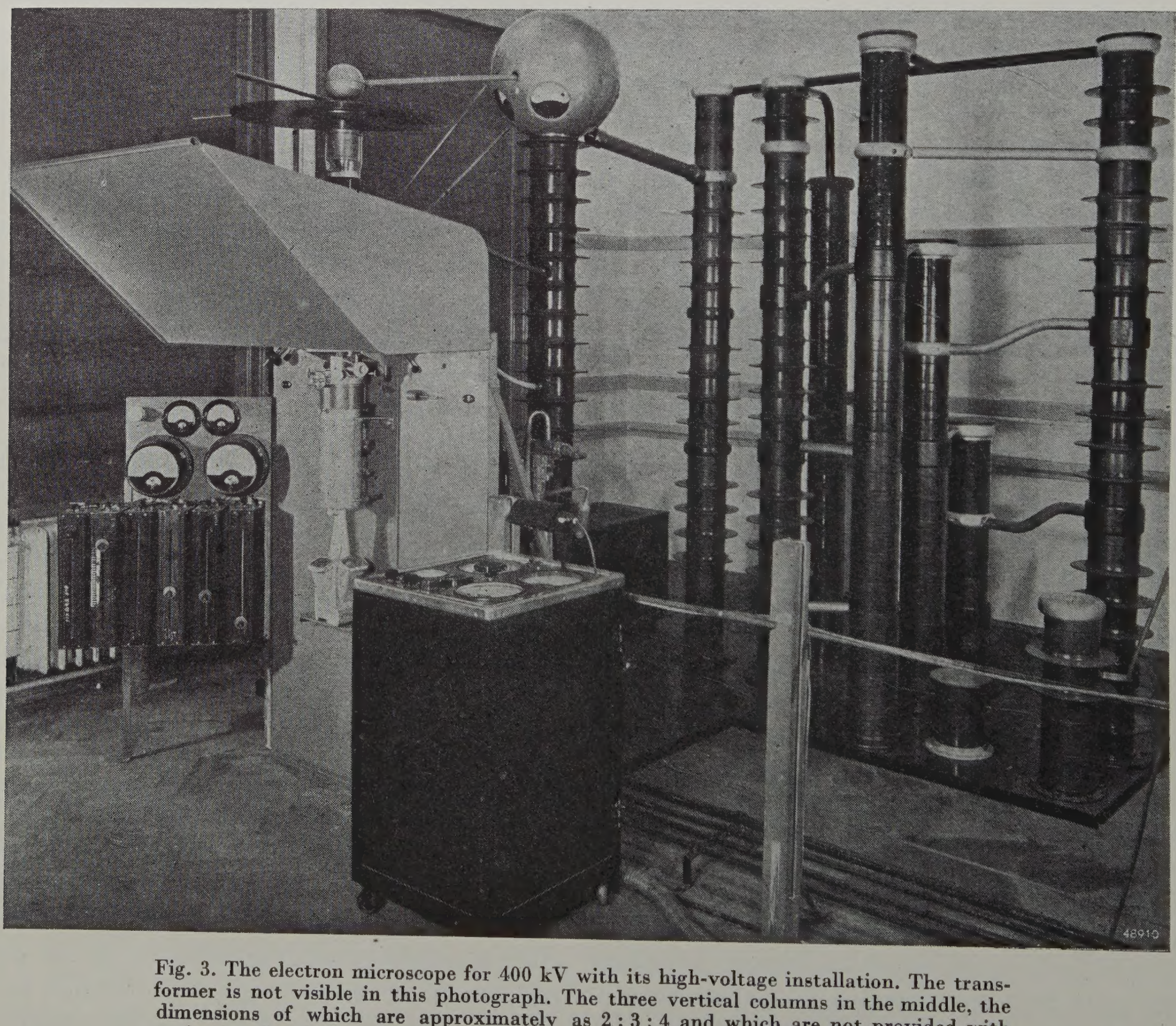

Fig. 3. The electron microscope for 400 kV with its high-voltage installation. The transformer is not visible in this photograph. The three vertical columns in the middle, the dimensions of which are approximately as 2 : 3 : 4 and which are not provided with projecting flat flanges, each contain two vacuum valves for 150 kV negative anode voltage. The other columns contain condensers and resistances. In the foreground is a control panel with various measuring instruments. Behind it is a box containing the generator for the high-frequency heating of the cathodes of the valves. On the extreme left are the variable resistances for the current control of the magnetic lenses.

the end of the hole in the third anode the electrons strike the anti-cathode. In order to reduce the length of a unit and still prevent creeping discharges there are double folds in the glass wall. To prevent direct sparking the annular-shaped hollows between the folds are filled up with an insulating body of "Philite".

The acceleration tube of our electron microscope is constructed on exactly the same principle, so that for further particulars we may refer to the article in question. The acceleration of the electrons here, however, takes place in three instead of in six stages. If it were later desired to use still higher voltages in the electron microscope it is possible to alter or to extend this component without great difficulty.

The cathode emitting the electrons is fed from a 6-volt accumulator battery. It can be displaced somewhat with respect to the other electrodes in order to make it possible to direct the beam accurately. The focussing cap has a variable voltage, negative with respect to the filament, which is important for obtaining a narrow beam of electrons.

Much care must be devoted to the accurate adjustment of the position and direction of the beam striking the specimen, because of the great influence of these factors on image quality. For that reason the accelerator tube with condenser is made adjustable, as to direction and position with respect to the microscope tube, by means of screws. In the photograph of *fig. 4* the protecting screen has been removed from the microscope in order to show the acceleration tube clearly.

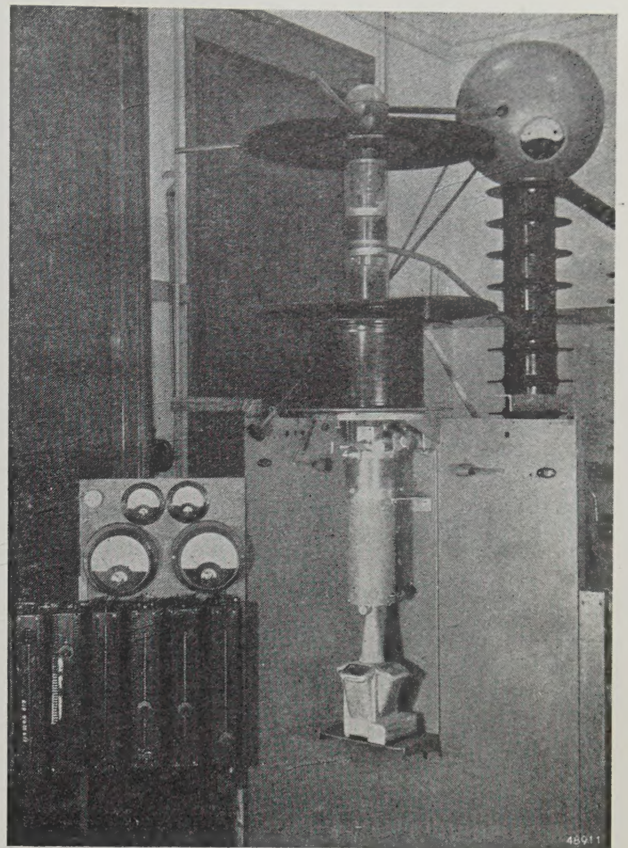

Fig. 4. The microscope proper with the acceleration tube. The protecting plate has been removed to show clearly the acceleration tube. On the right is a column containing the resistances for the potentiometer from which the current for the tube is tapped. On top of this column, in a metal sphere at a potential of —400 kV with respect to earth, is a 6-volt accumulator for the heating of the filament.

The microscope

In the description of the microscope proper we can also be brief, since in various respects its construction corresponds to that of the electron microscope for 150 kV described in the article cited in footnote [1]).

Fig. 5 shows the microscope with the acceleration tube in cross section. The condenser lens is above the microscope at the lower end of the acceleration tube. In addition to the condenser there are four lenses: an objective, two intermediate lenses and a projector. The introduction of an intermediate lens has the advantage that the length of the tube is kept small in relation to the magnifications reached, the magnification being variable within a wide range. The distance from the condenser to the final screen is 93 cm. The magnification is c o n t i n u o u s l y variable from 2000 to 100 000 diameters, the projector being left unaltered so that the whole image field with a diameter of 9 cm is always filled [5]).

At the time that this microscope was designed, from what was known about the subject it was to be expected that the resolving power of photographic emulsions and fluorescent screens would decrease to a not unimportant extent upon applying a higher acceleration voltage. It was therefore decided to design the instrument for a magnification of 10^5 diameters. In order to attain this with a short overall length of the microscope it was considered advantageous to use f o u r stages, *i.e.* to introduce t w o intermediate lenses besides objective and projector. With the photographic emulsions and fluorescent screens now available the resolving power is so good that at high voltages it will be possible to work with a lower magnification than was originally intended. Satisfactory results can then be obtained with three stages, using one intermediate lens. It is planned in that case to replace the upper intermediate lens by a

[5]) This is explained more fully in the article referred to in footnote [1]).

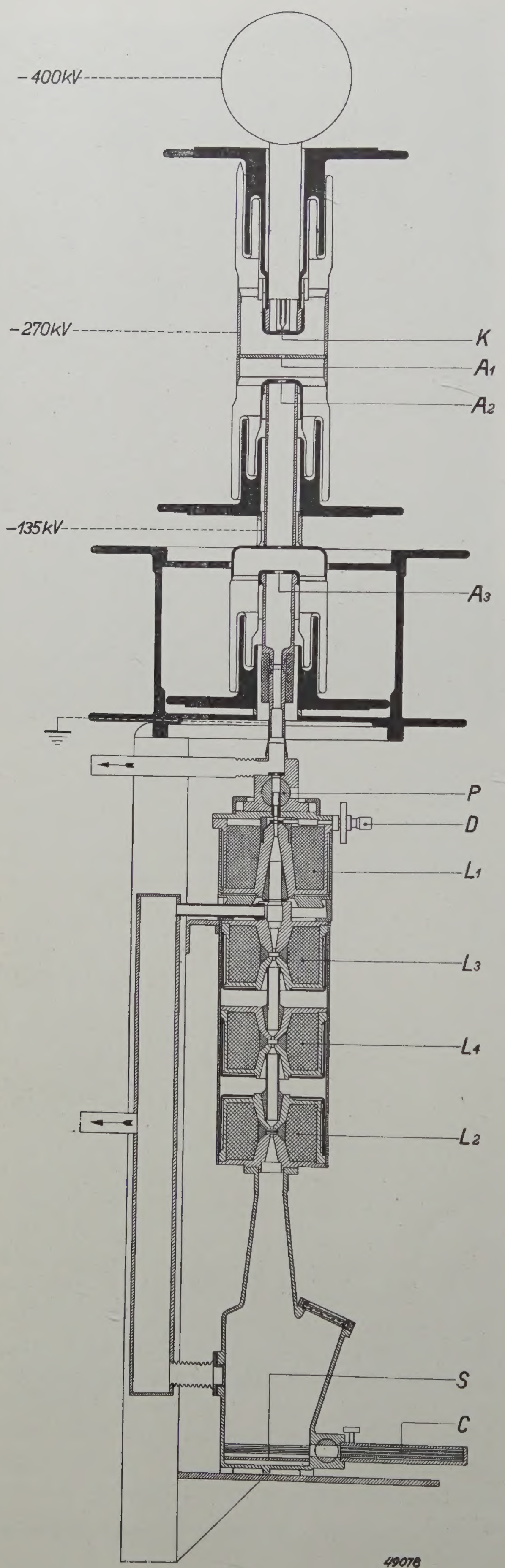

Fig. 5. Sectional view of the microscope with the acceleration tube (scale about 1 : 8). K is the cathode, A_1, A_2 and A_3 are the three anodes, P the lock for the specimen, D the objective aperture. L_1 is the objective, L_2 the projector, while L_3 and L_4 are the two intermediate lenses. S is the fluorescent screen and C the plate holder of the photographic camera. At the left of the figure it is indicated what part of the acceleration tube is connected with earth and where the potential difference with respect to earth amounts to —135, —270 and —400 kV respectively.

diffraction lens as used in the above-mentioned 150 kV microscope.

As regards the construction of the lenses it may be noted that the shape of the iron cores is so chosen that saturation cannot occur. It should also be mentioned that, in view of the possible future use of higher acceleration voltages the microscope is so constructed that electron rays with an energy of a million volts can be employed.

We have already called attention to the fact that when using an electron microscope with a high acceleration voltage it is essential to take care to use an objective aperture best suited to the nature of the object to be studied. In order to make this possible four tungsten objective diaphragms, of different sizes and adjustable from the outside, are provided, the diameters of the openings being respectively 0.8, 0.08, 0.045 and 0.03 mm.

Finally a few remarks concerning the vacuum system. When the electron microscope is in use the pressure in the acceleration tube may not be higher than about 0.001 mm Hg. In order to attain this vacuum two independent high-vacuum pump systems are used. The vacuum is measured with a Philips vacuum meter [6]) with a glowdischarge tube, to be used in the interval from 10^{-5} to 10^{-3} mm of mercury.

When a new specimen is to be examined it is introduced into the tube by means of an air lock in the object stage. Only about 2 cm³ of air enters the microscope when this is done. Twenty seconds after closing the lock the vacuum has again reached a value permitting the high voltage to be switched on.

Five reproductions on the following pages give some idea of the results which have been obtained with the electron microscope for 400 kV. *In figs. 6, 7* and *8* yeast cells are shown; it should be mentioned that these pictures have no biological importance in themselves but merely illustrate the effect of high voltage in connection with specimens.. The exposures were made with acceleration voltages of 112, 225 and 350 kV respectively. The appearance of these pictures confirms the

[6]) F. M. Penning, Philips Techn. Rev. 2, 201-208, 1937.

statement at the beginning of this article about the advantages to be expected from the use of a high acceleration voltage with thick specimens. *Figs. 9* and *10* demonstrate the influence of the objective diaphragm on the contrast obtained.

The electron microscope for 400 kV described here is of an experimental type. Improvements and refinements are being constantly made and further investigations are being continued.

We shall conclude this article with a discussion of the measures which have to be taken to protect the observer against X-radiation.

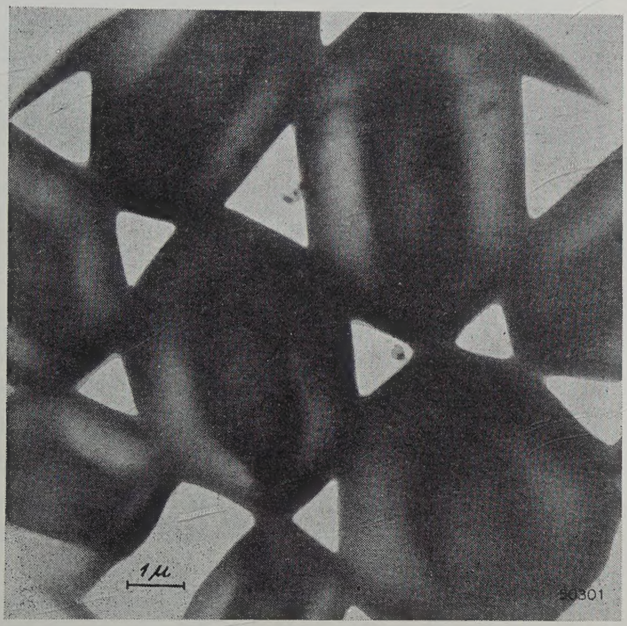

Fig. 6. Yeast cells photographed with an acceleration voltage of 100 kV, diameter of objective diaphragm 0.08mm. Magnified electron-optically 2000×, total magnification 5000×. The cells are transparent, but the internal structure is blurred. In order to indicate the true magnification of the reproduction the length 1μ is shown in this and the following figures.

Protection against X-rays

Wherever electrons collide with matter X-rays are excited. It is sufficiently well known that exposure to X-rays for too long a period or a too intense radiation may have very harmful results on the human body. Precautions must therefore be taken that the amount of X-radiation reaching the operator of an electron microscope is kept below a certain safe limit. This is usually done by introducing between the source of X-radiation and the observer protective material which absorbs most of the X-rays. Complete absorption is impossible, but also unnecessary.

In the case of instruments with a very low voltage, for instance up to 20 kV, the X-rays are very soft, and thus easily absorbed. The wall of the vacuum tube and the surrounding air therefore fulfil this function adequately. In the case of microscopes working with high voltages special measures must be taken to protect the observer against X-radiation. This is especially so when electrons of such high energy are used as in the case of the instrument in question.

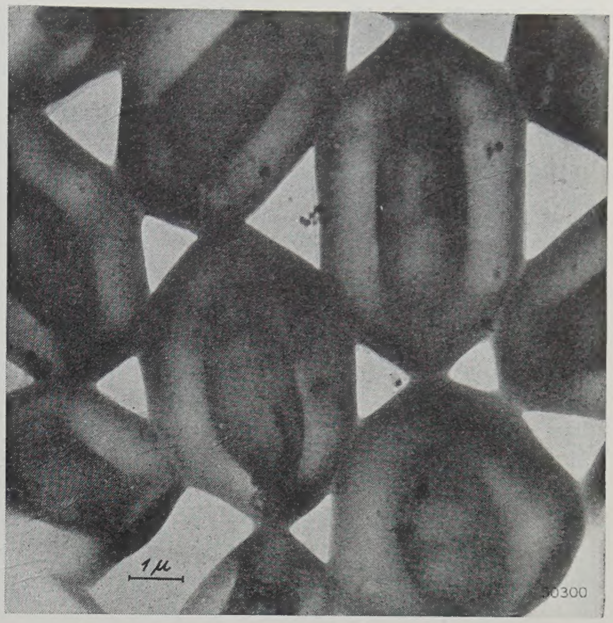

Fig. 7. Yeast cells, the same specimen as in fig. 6, with the same aperture and the same magnification, but with an acceleration voltage of 225 kV. The internal structure is now appreciably sharper.

Fig. 8. Yeast cells taken with an acceleration voltage of 350 kV. The objective diaphragm with a diameter of 0.08 mm was again used and the electron-optical magnification was again 2000 diam. Thanks to the use of the very small objective diaphragm the contrast is still sufficient with this energy, while finer structures are now also visible. Some thin dark lines to be seen on the right of the picture are images of folds in the collodium film on which the specimen is fixed..

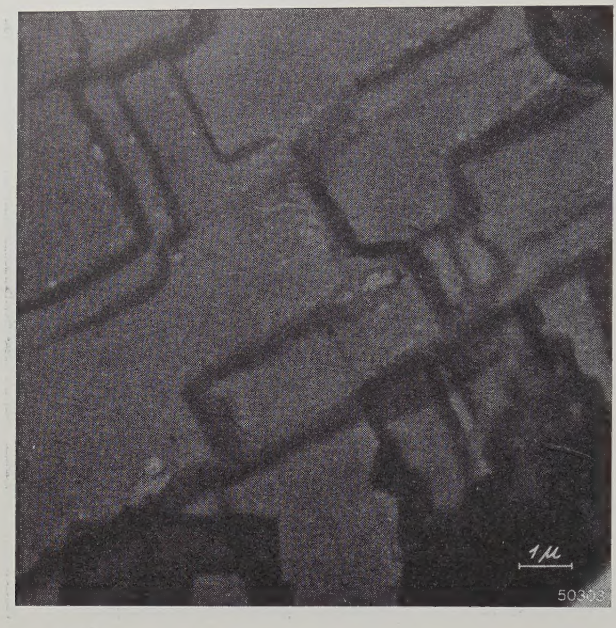

Fig. 9. Oxide film of an etched aluminium surface, taken with an acceleration of 250 kV and a diaphragm of 0.5 mm diameter. Electron-optical magnification 3000 diam.

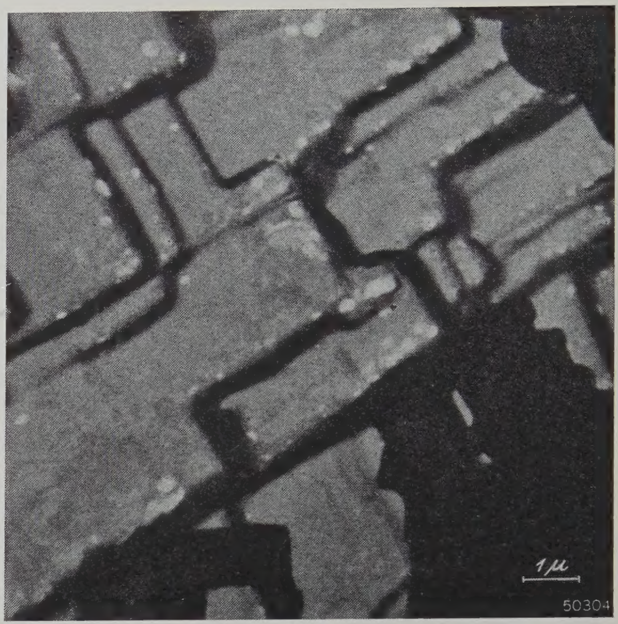

Fig. 10. The same specimen as in fig. 9 taken with the same acceleration voltage with the same magnification but with a diaphragm of 0.045 mm. The effect of the size of the diaphragm on the contrast is clearly visible.

The permissible daily tolerance is usually considered to be 0.2 r [7]), which for an eight-hour working day amounts to an X-ray intensity of about 10^{-5} r/sec.

The X-ray dose increases linearly with the current of the electron ray and with the atomic number of the material struck by the electrons, and, moreover, with the square of the energy of the electrons. For a source of radiation of small dimensions the radiation is inversely proportional to the source.

It is important to note that in an electron microscope the main source of X-radiation is at the diaphragms. When the electron beam has passed the condenser aperture the current is already considerably smaller, and this is even more so after the objective aperture has been passed. The current to the screen is so small — in our case only 10^{-8} to 10^{-9} A — that the X-radiation emitted there may be practically ignored. Therefore the protective screen, usually of lead, must be placed in front of the upper end of the microscope.

It is desirable, however, that the necessary protective measures to lower the intensity of the X-radiation should be taken in the construction of the instrument. In the electron microscope described here this has been done in two ways.

In the first place care has been taken that the current shall be as small as possible, *i.e.* not larger than what is necessary for the "illumination" of the part of the object to be projected. This current is fixed because of the fact a certain current density is necessary to obtain a clear image. Reduction of the current to this minimum amounts to working with a narrow electron beam which is carefully directed. It is always desirable to work with a narrow, well-directed beam, but it is an essential requirement when the acceleration voltage is high. Owing to the acceleration tube being long, the beam has a greater spread, and as a result of the high energy of the electrons an intense X-radation is thereby excited.

The second method employed for decreasing the intensity of the X-radiation consists in making the most important diaphragms of materials having a low atomic number. This is obtained by introducing a diaphragm made of beryllium both in the condenser and directly over the specimen. To promote the dissipation of heat the diaphragms are brassed into a copper fitting.

It is desirable to determine the thickness of the protective plate necessary to reduce the dose received by the observer to below the limit previously stated. In this we are helped by the investigations already made in connection with the protection of the operators of X-ray therapy equipment. An electron microscope can be compared to an X-ray installation having an anode voltage as high as the acceleration voltage of the microscope. On the basis of the investigations previously carried out the

[7]) A röntgen (r) is the dose of X-radiation which will free an e.s.u. of charge (3.3×10^{-10} coulomb) by ionization upon passing through 1 cm³ of air at a temperature of 20 °C and a pressure of 76 cm Hg. See also the article by B. van Dijk in Philips Techn. Rev. 4, 114-117. 1937.

thickness of the protective plate in the X-ray installation can be found, and from that it can be calculated how thick the plate must be in the case of the electron microscope, taking into account that the current of the electron beam in the microscope is much smaller than in the X-ray tube, and if necessary also allowing for a difference in atomic number between the materials struck by the electrons in the two instruments, and the distances at which the observers are situated from the X-ray source in both cases.

The graph of *fig. 11* relates to an X-ray tube for 400 kV, where a tungsten surface is struck by a current of 10 mA. These are the conditions prevailing in a certain installation for irradiation with X-rays [8]). It is found that the lead covering must be 24 mm thick to keep the dose received by the operator at a distance of 1 m below the value of 10^{-5} r/sec.

A current of 10 mA is normal in X-ray installations. With this electron microscope, under the above-mentioned conditions, a current of not much more than 0.02 mA is sufficient. In view of this the thickness of lead can be reduced from 24 to 8 mm. By using beryllium instead of tungsten for the diaphgrams a further reduction from 8 to 2.5 mm of lead is possible.

[8]) Philips Techn. Rev. **8**, 105 — 110, 1946 (No. 4).

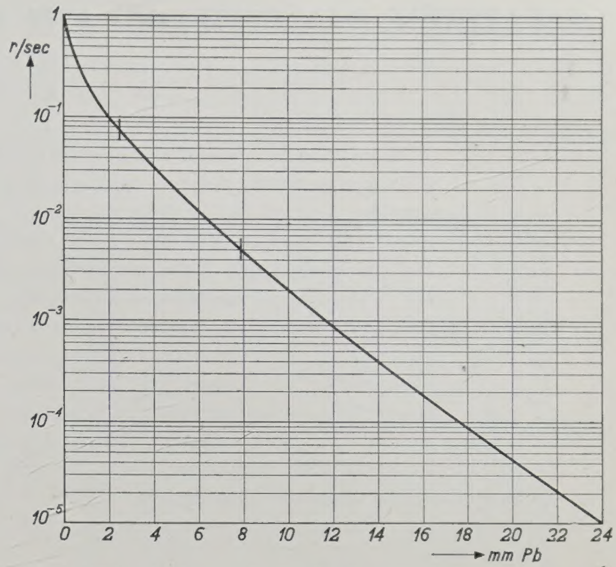

Fig. 11. The thickness of the lead protecting screen in millimeters necessary to keep the X-ray dose below a certain value when the anode voltage is 400 kV and the current is 10 mA, while the electrons impinge on tungsten and the observer is situated at a distance of 1 m from the source of radiation. When the current is reduced to 0.02 mA a lead thickness of about 8 mm is sufficient to keep the X-ray intensity below 10^{-5} r/sec; if, in addition, the diaphragms are made of beryllium a protection of slightly more than 2 mm of lead is sufficient.

On the the other hand in an electron microscope the distance from the source of X-radiation to the observer is usually less than 1 m. In determining the thickness of the lead protecting plate this must be taken into account.

A CATHODE-RAY OSCILLOGRAPH WITH TWO PUSH-PULL AMPLIFIERS

by E. E. CARPENTIER.

621.317.755

A description is given of the new cathode-ray oscillograph for universal use, type GM 3159, incorporating the new oscillograph tube DG 7-3. In this tube there is a push-pull amplifier for each pair of deflecting plates. A correction circuit ensures that within a frequency range of 10 - 460 000 c/s and with the maximum sensitivity the amplification is kept constant within 3 db; with reduced sensitivity this range is extended to over 10^6 c/s. With the introduction of an amplifier for the horizontal deflection it has been possible to arrange a very simple circuit for the time-base voltage. The saw-tooth voltage is also available for other purposes extraneous to the oscillograph, for instance for measuring amplifiers; the frequency of this voltage can be regulated between 10 and 150 000 c/s. When the time-base is used the light spot can be blanked out during the retrace, thus making the picture clearer. There is a considerable improvement in the magnetic screening of the oscillograph tube. The new oscillograph is smaller and much lighter in weight than the older types.

Cathode-ray oscillographs have been described several times already in this journal [1][2][3]). The type with which this article deals (the GM 3159) is distinguished from the others, *i.a.* by the fact that it has t w o amplifiers, one for the vertical deflection, as is usual, and another for the horizontal deflection. With this second amplifier the oscillograph is of more universal use. A second point of difference is the better quality of the picture, due for the greater part to a new type of oscillograph tube being used. In the third place it may be said that every endeavour has been made to keep the weight and dimensions of the whole apparatus as low as possible, with the result that a handy and inexpensive instrument has been produced.

This aim at small dimensions tends to come into conflict with the desire for high sensitivity and a wide frequency band, to give the instrument the widest possible field of application. For instance, to avoid an undesirable high temperature in an apparatus of small dimensions the energy dissipation has to be limited. This makes it necessary to use the smallest possible number of amplifiers, which in turn means on the one hand a compromise with the requirement of sensitivity and on the other hand leads to a high amplification per stage, at the cost of bandwidth. Compared with the oscillograph GM 3152 [2]) the compromise referred to has necessitated some concession in respect to sensitivity, especially at the very high frequencies. The new type is not intended for the field of very low frequencies (1-10 c/s) such as occur in mechanical applications; for this purpose the oscillograph GM 3156, specially designed for these low frequencies, is still indicated (see note [3]).

General aspects

Hitherto cathode-ray oscillographs have been designed mainly on the system represented in the block diagram of *fig. 1a*: the voltage to be oscillographed is connected at *I* and conducted *via* a variable attenuator (potentiometer) Z_1 to the amplifier A_v, which is connected to the plates D_v for the vertical deflection. The horizontal deflection is obtained by applying to the plates D_h a linear saw-tooth voltage induced by the time-base circuit *TB*. This is synchronised by an auxiliary voltage drawn, *via* an attenuator Z_2 and a switch *S*, either from the signal to be oscillographed (with the switch *S* in position *A*) or from an auxiliary signal connected at *II* (position *B*), or from the mains (position *C*), *via* the supply unit *P* furnishing the anode, grid and filament voltages for the various valves.

The new oscillograph has been designed somewhat differently. As already stated, the pair of horizontal deflecting plates also have a separate amplifier (A_h in fig. 1*b*). The switch *S* now has five positions, the third, fourth and fifth corresponding to the positions *A*, *B*, and *C* in the old system, except that the amplifier A_h is always in between the pair of plates D_h and the time-base unit. The latter unit now has to supply only a saw-tooth voltage of small amplitude, so that it can be made much simpler. This, however, is only an incidental advantage of the introduction of the second amplifier and finds expression particularly when the switch is in position *1*, when Z_2 is connected direct to the input of the amplifier A_h; the time-base unit is then cut off. As a consequence one is no longer restric-

[1]) Philips Techn. R. 1, 147 — 151, 1936 (type GM 3150).
[2]) Philips Techn. R. 4, 198 — 204, 1939 (type GM 3152).
[3]) Philips Techn. R. 5, 277 — 285, 1940 (type GM 3156).

ted to the observation of actual oscillograms (with the voltages as a function of time), for now also Lissajous figures (*fig. 2*) can be oscillographed, a voltage being pictured as a function of any other voltage; thanks to the presence of two amplifiers both input voltages may be small. This considerably expands the scope of the instrument, for instance for measuring frequencies of phase angles. Finally, with the switch S in position *2* a voltage with the mains frequency is conducted to the amplifier A_h *via* a separate attenuator Z_3; in this position, too, the time-base unit is switched off.

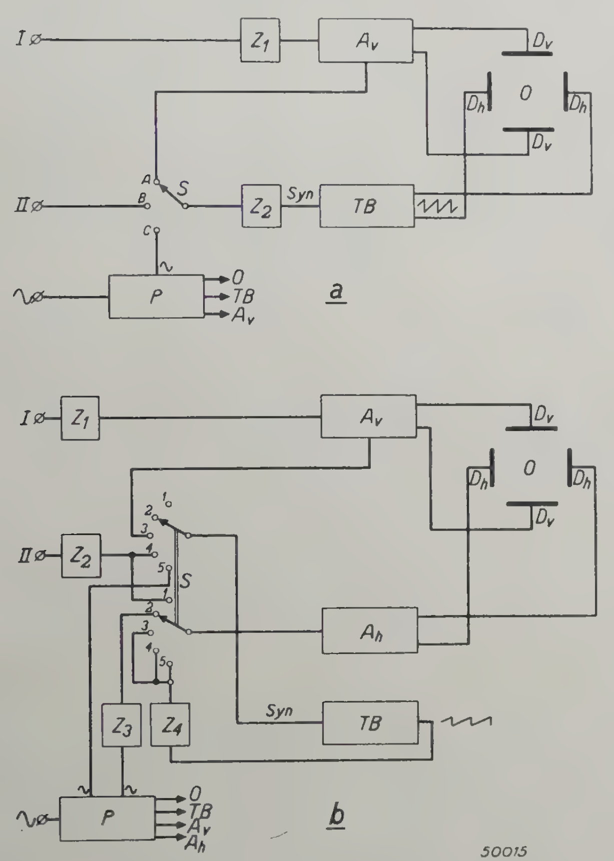

Fig. 1. *a*). Block diagram of cathode-ray oscillographs hitherto commonly used. I — input connection for the voltage to be oscillographed. Z_1 — variable attenuator (potentiometer). A_v — amplifier. O — oscillograph tube with plates D_v for vertical deflection and D_h for horizontal deflection. TB — time-base unit, the frequency of which can be synchronised with an auxiliary voltage carried in at Syn *via* the attenuator Z_2 and the switch S. This voltage is either drawn from the voltage to be oscillographed (S in position A) or is carried in at II (position B), or is taken from the mains (position C). P — supply unit connected to the mains.

b): Block diagram of the new oscillograph (GM 3159). The plates D_h are connected to an amplifier A_h (identical with A_v) whose input, when S is in position *1*, is connected to the terminals II, so that a small voltage can be oscillographed as a function of another small voltage (both of the order of 10 mV). When S is in position *2* a sinusoidal voltage of the mains frequency is fed to the amplifier A_h. Positions *3*, *4* and *5* of S correspond to the positions A, B and C in fig. 1*a*. Z_3 and Z_4 are attenuators. The rest of the symbols have the same meanings as in fig. 1*a*.

In both systems (*a*) and (*b*) the plates D_h can be connected direct to a pair of terminals.

So much then for the general layout of the new oscillograph. We shall now examine some of the principal components, very briefly the cathode-ray tube, then in more detail the amplifiers and the circuiting of the time-base voltage. Finally we shall discuss some features of the mechanical construction.

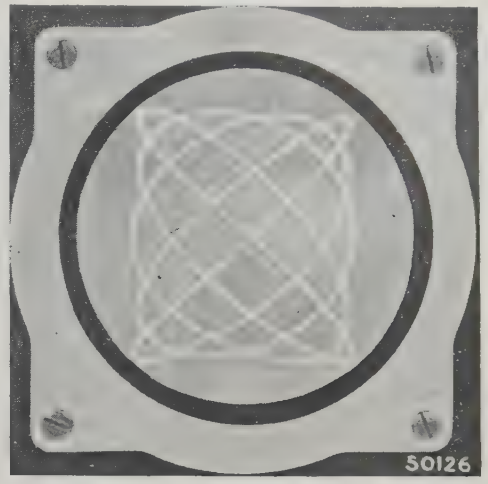

Fig. 2. Lissajous figure demonstrating 1) that the light spot retains its sharpness over the whole area of the screen and 2) that the picture fits in a rectangle. The latter is due to the symmetrical control of the two pairs of deflecting plates, avoiding trapezoidal distortion (see the article referred to in note [2]).

The cathode-ray tube

The new oscillograph is fitted with the DG 7-3 cathode-ray tube, which incorporates the various improvements described in the last number of this journal [4]). This tube has a sharper light spot, especially at the edge of the screen, with the result that although the screen is only 7 cm in diameter a sharp picture is obtained of practically the same size as that produced with the older tubes having a screen diameter of 9 cm. The Lissajous figure in fig. 2 shows the uniform sharpness of the line over the whole screen.

Then there is the electrical screening between the two pairs of deflecting plates and their leads, thanks to which the parasitic capacitors between the pairs of plates are reduced to such an extent that even at very high frequencies there is no noticeable influence of one pair of plates upon the other, so that there is no tendency of a voltage between one pair to induce a voltage between the other pair.

[4]) J. de Gier and A. P. van Rooy, Improvements in the Construction of Oscillograph Tubes, Philips Techn. R., 9, 181 — 185, 1947 (No. 6).

The amplifiers

Push-pull amplificitation

Since the amplifiers for both pairs of deflecting plates are identical, a description of one of them suffices.

Asymmetric control, where one of the plates is earthed, causes distortion of the picture (see for instance the article quoted in footnote [2]). In order to avoid this distortion the amplifier has been built on the push-pull principle. A pre-stage has been dispensed with, because the number of valves and the dissipated energy had to be kept as low as possible in order to meet the desire for an apparatus of small dimensions. The question, then, was how to get a symmetrical output voltage with a push-pull circuit to which an asymmetric input voltage is applied (earthed on one side). *Figures 3a* and *b* show two ways of solving this problem. In the first method the amplifier B_2 is fed from a voltage-divider, formed by two resistors R_b and R_{g2}, in series with a separating capacitor C_3 applied across the output of the valve B_1. The ratio of these resistances should be as $(g_0 - 1) : 1$, where g_0 is the voltage amplification of one half of the push-pull.

In the method according to fig. 3*b* absolute symmetry is not obtained, it is true, but it is very closely approximated. The principle underlying this method is that the difference between the two anode currents (these being unequal in the case of asymmetry) is caused to flow through an impedance Z_k in the common cathode lead, thereby inducing in that impedance an alternating voltage which acts on the two grids in the same sense. A simple calculation shows that symmetry is very closely approximated if the condition $SZ_k \gg 1$ (where S = the slope of the valves) is satisfied.

The following equations may be written for the alternating voltages and currents occurring in the system of fig. 3*b*, with the symbols and choice of positive directions given there:

$$\left.\begin{array}{ll} \text{Tube } B_1 & \text{Tube } B_2 \\ V_{g1} = V_1 - Z_k I_k, & V_{g2} = Z_k I_k, \\ I_{a1} = S V_{g1} & I_{a2} = S V_{g2}, \\ I_{k1} = \beta I_{a1}, & I_{k2} = \beta I_{a2}. \end{array}\right\} \quad \ldots \quad (1)$$

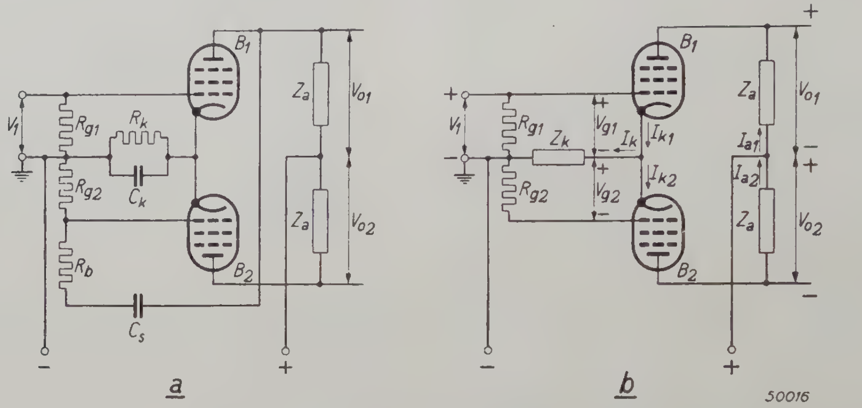

Fig. 3. Two methods of obtaining from a push-pull amplifier a symmetric output voltage ($V_{o1} = V_{o2}$))notwithstanding an asymetric input voltage (V_1).
a) A voltage divider formed by the resistors R_b and R_{g2} conducts a part of the output voltage V_{o1} from the amplifying valve B_1 to the control grid of the valve B_2. C_s is a separating capacitor, R_k a resistor shunted by a capacitor C_k for supplying the negative grid voltage.
b) With this method symmetry is obtained approximately when $SZ_k \gg 1$ (S = slope of the valves B_1 and B_2, Z_k = impedance of the common cathode lead). The currents indicated in the diagram as I_{k1}, I_{a1}, etc. are alternating currents, and the voltages V_1, V_{g1}, V_{o1}, etc. are alternating voltages; they are reckoned to be positive in the direction of the arrow or in the direction marked + and —.

Here the factor β, which generally has a value of 1.2 — 1.3, indicates that the cathode alternating current is higher than the anode current; the difference between these two flows across the screen grid.

Further the equation holds:

$$I_k = I_{k1} - I_{k2}.$$

Hence:

$$\left.\begin{array}{l} I_{a1} = \dfrac{1+\beta S Z_k}{1+2\beta S Z_k} S V_1, \\ I_{a2} = \dfrac{\beta S Z_k}{1+2\beta S Z_k} S V_1. \end{array}\right\} \quad \ldots\ldots\ldots \quad (2)$$

From these equations it is seen that the anode currents differ less according as $\beta\ SZ_k$ is greater than unity. If $I_{a1} \approx I_{a2}$ then, given equal anode impedances Z_a, naturally also $V_{o1} \approx V_{o2}$.

Which of the two methods is the more suitable for our purpose will be left unanswered for the moment; we shall revert to it after discussing the frequency characteristic.

Amplification required; value of the anode resistance

Between the plates of the more sensitive of the two deflecting systems (*i.e.* the pair of plates closest to the anode) a peak voltage of 20 V is needed for a total deflection of 1 cm. Reckoning on a sensitivity of 1/25 cm picture height or width per mV (r.m.s.) being required at the input of the amplifier, then an amplification of $20(/25\sqrt{2} \times 10^{-3}) = 560$ is needed. Therefore each half of the push-pull must yield an amplification of $560/2 = 280$.

When a pentode is used the amplification equals the product of the impedance Z_a in the anode circuit and the slope S. In the pentode used here (the EF 50) the slope is adjusted to approx. 4 mA/V, so that to get an amplification of 280 Z_a must be 70 000 ohms.

Z_a consists of a resistance R_a and a parasitic capacity C_p connected in parallel, the latter being taken at about 28 pF. So long as the frequency is not too high the effect of C_p may be ignored, so that then $R_a \approx Z_a = 70\ 000$ Ohms. At a frequency, however, of say 10^6 c/s — which we shall take, for the present, as the upper limit of the frequency band — the impedance of the parasitic capacity has dropped to 5700 Ohms, which is small compared with R_a, so that then $|Z_a| \approx 1/\omega C_p$ and the amplification has dropped accordingly. How this problem is met will be shown farther on; first we shall see how the choice of the anode direct current and of the direct voltage for feeding the anode circuit is mainly determined by the value of $1/\omega C_p$ at high frequencies and by the size of picture required.

Anode direct current; feed voltage

If at high frequencies a picture height of say 3.5 cm suffices, then the amplifier has to give a voltage with a peak value of $3.5 \times 20 = 70$ V, thus 35 V for each half. At the highest frequency of 10^6 c/s, when $|Z_a| \approx 5700$ Ohms, there is an anode alternating current with a peak of $(35/5700) \times 10^3 = 6.1$ mA. The anode direct current must therefore be at least equal to that value; to leave some reserve 6.5 mA has been chosen.

The voltage required for feeding the anode circuits is found in the following way; this feed voltage is roughly equal to the minimum admissible anode voltage of the pentode EF 50 (approx. 100 V) plus the maximum voltage loss in the anode resistance. This latter resistance consists of the sum of the direct voltage loss — amounting to $6.5 \times 10^{-3} \times 70\,000 = 455$ V — and the peak value of the maximum alternating voltage that each half of the amplifier is required to yield, *viz.* about 35 V. Thus we arrive at a sum of $100 + 455 + 35 = 590$ V. A certain allowance has to be made, however, for mains voltage fluctations, leakage of anode current and leakance of the anode resistance. In this way we reach a figure of 675 V for the feed voltage. This voltage together with the above mentioned anode current of 6.4 mA for each of the four amplifying valves gives for a large part the total dissipation of energy. The feed voltage of 675 V is also used for the cathode-ray tube.

The frequency characteristic

The shape of the frequency characteristic of the amplifier depends upon the variation of $|Z_a| = R_a/\sqrt{1 + (\omega C_p R_a)^2}$ with the frequency. In *fig. 4* curve *a* represents $|Z_a|/R_a$ where the maximum value is taken as 100%. As is seen, this curve is not very satisfactory. In order to improve this, a new method has been followed which will be explained with reference to *fig. 5*, where the push-pull circuit is temporarily dispensed with.

The anode alternating current I_a is split up into two components, I_R and I_C, which flow respectively through R_a and C_p; I_C is 90° in advance of I_R. When the control grid voltage V_g has a constant amplitude and increasing frequency I_a remains constant at the value SV_g, but I_C increases at the cost of I_R, so that the voltage supplied $|V_o| = I_R R_a$ drops. This voltage would be independent of the frequency if the valve could also supply, in addition, the capacitive current I_C. This can be achieved by feeding the valve with an additional

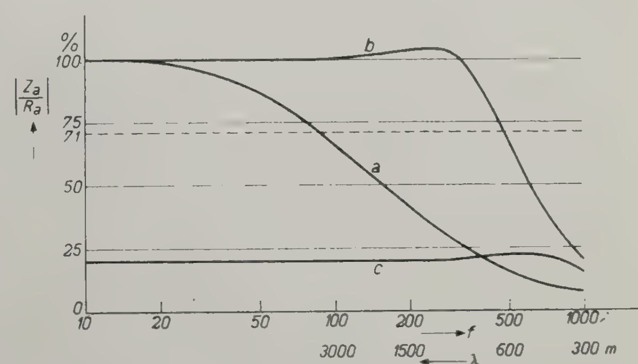

Fig. 4. The ratio $|Z_a|/R_a$, to which the amplification is proportional, as a function of the frequency f (in kc/s). Curve *a*: resistance amplifier without correction. The drop in amplification as the frequency increases is due the decrease of the anode impedances Z_a resulting from the presence of parasitic capacity. Amplification drops to 71% already at 85 kc/s. *b*) By applying a correction the frequency range within which the amplification lies between 100% and 71% is extended to about 460 kc/s. *c*) By connecting a resistor (R_p in fig. 7) parallel across the output terminals the upper frequency limit is raised to over 1000 kc/s, at some sacrifice of sensitivity.

On the ordinate axis 100% corresponds to an amplification of about 560. On the axis of abscissae several wavelengths (λ) are shown.

input voltage of a suitably chosen value and phase, as shown in fig. 5: in (a) V_1 is the original voltage that is to be amplified and V_b the extra input voltage (which has to satisfy a certain condition

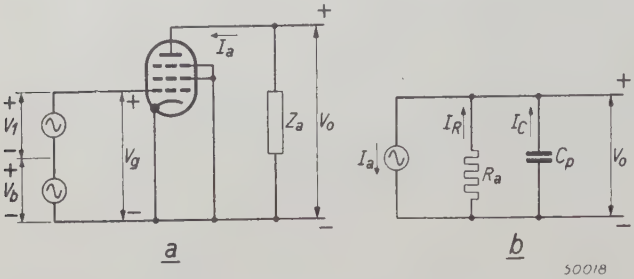

Fig. 5 a) A pentode, to the control grid of which an auxiliary voltage V_b is applied (in addition to the voltage V_1 to be amplified) with the object of compensating the loss of amplification at high frequencies due to parasitic capacity. Direct voltage sources are omitted in this and the following diagrams. The + and — signs indicate the directions in which the alternating voltages V_1, V_b, V_g and V_o are considered to be positive; the positive current direction is indicated by a single arrow.
b) Replacement diagram for the anode circuit of fig. 5a: the current source I_a feeds the parallel circuit of R_a and C_p.

to be specified later), so that the total grid alternating voltage $V_g = V_1 + V_b$. As is known, in so far as the anode circuit is concerned one may imagine a pentode as being replaced by a source of current of the strength $I_a = SV_g = S\,(V_1 + V_b)$ — see fig. 5b. When the positive directions are chosen as indicated in the illustration the current I_R in the resistance is then:

$$I_R = \frac{-V_o}{R_a} = \frac{Z_a I_a}{R_a} =$$

$$= \frac{R_a/(1 + j\omega C_p R_a)}{R_a} \cdot S(V_1 + V_b) = \frac{S(V_1 + V_b)}{1 + j\omega C_p R_a}.$$

To give I_R the value that is really desired, $i.e.$ SV_1, it is therefore necessary to chose V_b such that

$$\frac{S(V_1 + V_b)}{1 + j\omega C_p R_a} = SV_1,$$

or

$$V_b = j\omega C_p R_a V_1 = -\frac{j\omega C_p}{S} \cdot V_o. \quad . \quad (3)$$

The extra voltage V_b must therefore be 90° advanced in phase with respect to the output voltage and increase proportionately with the frequency.

This desired extra voltage can be obtained approximately by following the scheme of *fig. 6*, where a voltage divider C_b-R_g is applied across the output. At R_g a voltage $V_b' = V_o \cdot R_g/(R_g + 1/j\omega C_b)$ is obtained, which expression at $\omega C_b R_g \ll 1$ can be approximated by $j\omega C_b R_g \cdot V_o$. From a comparison with (3) we see that the desired effect can be obtained by choosing $C_b R_g = C_p/S$ and turning the voltage V_b' another 180° in phase.

Let us now return to fig. 3a, where it is shown how, with the aid of a voltage divider R_b-R_{g2}, a push-pull circuit can be supplied with a symme-

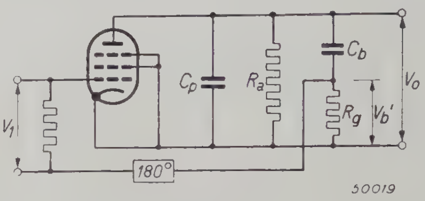

Fig. 6. The voltage V_b' tapped from the voltage divider C_b-R_b needs turning 180° in phase to serve as the compensating voltage V_b of fig. 5a.

trical voltage notwithstanding the fact that the input voltage is asymmetric. It is obvious to combine this voltage divider with the voltage divider C_b-R_g in fig. 6. The 180° phase shift required in the scheme of fig. 6 can be dispensed with if the voltage to be amplified, V_1, and the voltage tapped from R_g are conducted to different valves, as illustrated in *fig. 7*. R_b of fig. 3a and C_b of fig. 6 come to lie parallel; R_g of fig. 5 is called R_{g2} in agreement with fig. 3a. As regards the working of the system according to fig. 7 it may be roughly said that at "low" frequencies ($i.e.$ where the influence of C_b is negligible) it changes over to that of fig. 3a and that at "high" frequencies (where R_b can be ignored) it corresponds to the system of fig. 6 (where the 180° phase shift is brought about by the push-pull circuit).

This system, however, still has an important shortcoming. Though R_b and R_{g2} may be chosen of such values that at low frequencies the voltage

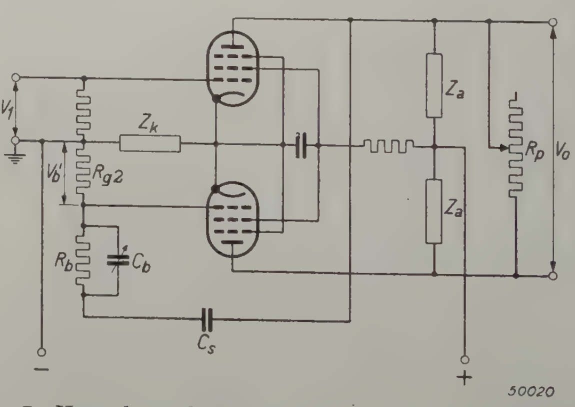

Fig. 7. Here the voltage dividers R_b-R_{g2} of fig. 3a and C_b-R_g of fig. 6 are combined into one (R_b, C_b) - R_{g2} for improving the frequency characteristic at high frequencies. The impedance Z_k has the same function, at high frequencies, as in the scheme of fig. 3b. C_s is a separating capacitor. The smaller the resistance R_p the less is the amplification but it is more constant at high frequencies; the maximum and minimum values of R_p correspond respectively to the characteristics b and C of fig. 4.

is symmetrical, at higher frequencies this will no longer be the case, for the valve B_2 (fig. 7) has to supplement the deficit in amplification of B_1 caused by the drop in Z_{a1}. In fig. 3*b*, however, we have another means of making a push-pull amplifier symmetric, by choosing for SZ_k a value greater than unity. This is in fact what has been applied in the amplifiers of the oscillograph GM 3159. Briefly it may be said that use has been made both of the method according to fig. 3*b* as well as that of fig. 3*a*, except that in the latter system instead of a potentiometer ratio of R_{g2}/R_b (which is independent of frequency) a ratio is applied which is dependent upon the frequency, to the extent that the amplification at high frequencies deviates less from the nominal value; the danger of the symmetry being thereby disturbed is obviated by choosing a value for SZ_k greater than unity.

Since S is a fixed quantity, this means that Z_k has to be chosen sufficiently large. And this applies only for high frequencies, since at low frequencies the system is identical with that of fig. 3*a*, where no account need be taken of Z_k. Consequently Z_k consists mainly of the reactance of a choke coil, and for the rest a resistance required to induce the desired negative grid voltage.

The extent to which the frequency characteristic is improved by this method may be seen from fig. 4, curve *b*: the frequency at which the amplification of 3 db drops to $^1/_2\sqrt{2}$ times the nominal value (thus 71%) has been raised from 85 c/s to approx. 460 c/s. Fig. 7 shows another special feature, the variable resistance R_p between the output terminals. The smaller R_p, the smaller the amplification but the more constant at high frequencies. With R_p at its minimum the characteristic *c* of fig. 4 is obtained where the amplification drops to 71% of the normal value around 1000 kc/s. Thanks to this resistance it is therefore possible to work also in the 500-1000 kc range with a fairly constant amplification, though a larger input signal is required for the same picture height.

Analysis of the push-pull circuit with correction.

Needless to say, the above more or less approximative statements have to be more carefully analysed to reach the best results. Here we shall show how some of the calculations work out.

For the lowest frequency to be considered the quantities $\omega C_b R_b$ and $2\omega\, C_p R_a$ should be smaller than unity, whilst $R_b \approx (g_0 - 1)\, R_{g2}$, in which $g_0 = SR_a$ = half the total nominal amplification.

At high frequencies $\omega C_b R_b$ must be greater than unity. Between V_b and V_o, according to (3), a phase difference of 90° is needed, and this is approximately obtained when $g_0 \gg 1$ and $C_b = 2C_b/SR_{g2}$. The absolute value g of the total amplification is then:

$$g = \left|\frac{V_o}{V_1}\right| = 2g_0 \sqrt{\frac{g_0^2 + (\omega_p C_p R_a)^2}{(g_0 - \omega^2 C_p^2 R_a^2)^2 + (\omega C_p R_a)^2}}\,. \quad (4)$$

For a non-corrected amplifier (not having C_b and R_b), provided $\beta SZ_k \gg 1$:

$$g = \frac{g_0}{\sqrt{1 + (\omega C_p R_a)^2}}\,.$$

For $\omega = 1/C_p R_a$ in this case the amplification is reduced by a factor $\sqrt{2}$; if we call this angle frequency ω' then (4) may be written as follows:

$$g = 2g_0 \sqrt{\frac{1 + \left(g_0 \cdot \frac{\omega'}{\omega}\right)^2}{1 + \left(g_0 \cdot \frac{\omega'}{\omega} - \frac{\omega}{\omega'}\right)^2}}\,.$$

This function is practically constant, *i.e.* $= 2g_o$, within a wide frequency range, but as the frequency rises it ultimately begins to drop. It becomes a factor $\sqrt{2}$ smaller at an angular frequency ω'', which amounts to approximately $1.5\sqrt{g_0} \times \omega'$. The bandwidth within which the amplification is greater than $2g_0/\sqrt{2}$ is therefore enlarged by the correction by approximately a factor $1.5\sqrt{g_0}$. Such a high factor, however, will not be attained in practice, due to several causes, the explanation of which would lead us too far afield here. Nevertheless, the factor that is attainable, in the present case amounting to 460 kc/s : 85 kc/s = 5.4, is appreciably greater than what can be reached with the method described in the article quoted in footnote [2]); there the drop of Z_a with increasing frequency was counteracted by introducing additional elements (*e.g.* one or two coils and a capacitor) in each anode impedance, by which means the bandwidth can only be increased by a factor no greater than about 3 without involving further difficulties, which we cannot enter into here.

The generator for the time-base voltage

In the article quoted in footnote [1]) a system is described for generating the time-base voltage by employing three valves. In the new oscillograph it has been possible to simplify this arrangement considerably, generating the time-base voltage with only one valve, though amplification is needed to get sufficient amplitude, which is achieved by means of the amplifier A_h (fig. 1*b*). Really, therefore, use is again made of three valves, but two of these (those of the amplifier) serve for other purposes too, which is not the case in the old system.

The principle of the system is as shown in *fig. 8*.

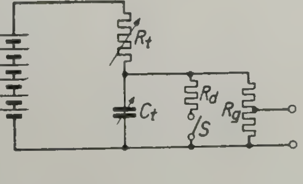

Fig. 8. Diagram of the time-base circuit. The capacitor C_t is charged from a voltage source E_0 *via* a variable resistance R_t and discharged (when the switch S is closed) *via* the much smaller resistance R_d. Actually S is a valve (see fig. 9*a*). R_g = input potentiometer of an amplifier.

When the switch S is opened then a capacitor C_t is charged *via* a resistance R_t from a direct voltage source E_0, and when the switch is closed this capacitor is discharged *via* the resistance R_d. Actually the function of the switch is performed by a valve, which will be referred to presently.

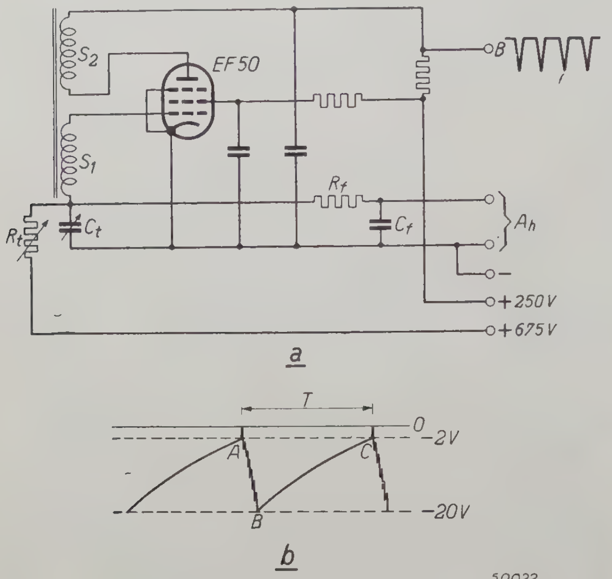

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Fig. 9. *a*) Diagram of the generator for the time-base voltage. *b*) Behaviour of the voltage on the grid capacitor C_t. The pentode EF 50 is brought into the squegging state by the back-coupling S_2-S_1. The grid current then soon charges C_t sufficiently for the resultant negative grid voltage (20 V) to block the anode current (curve AB in *b*). C_t discharges itself *via* the resistance R_t (curve BC in *b*) until at about —2 V oscillation starts again. Owing to R_t being connected to a point with a high positive potential, a practically linear voltage BC is obtained. The voltage on C_t is conduced *via* a filter R_f-C_f — which cuts out the high oscillating frequency — to the amplifier A_h for the horizontal deflection (*cf.* fig. 1*b*). At B voltage impulses can be drawn off for suppression of the electron beam during the retrace.

Both in the charging and in the discharging of C_t the voltage e_c behaves as an exponential function of time, so that in essence it is not linear. Consequently the horizontal velocity of the light spot on the screen will not be constant when e_c is conducted to the plates for horizontal deflection. The degree of this non-linearity, however, is insignificant when the amplitude E_c of the voltage e_c is kept small in comparison with E_0.

A simple calculation shows that the percentage of velocity variation D while the light spot is travelling from left to right may be written as:

$$D = \frac{E_c}{E_0} \cdot R_t \cdot \left(\frac{1}{R_t} + \frac{1}{R_g}\right).$$

where $D = (v - v')/v$ with v = initial velocity, v' = the velocity at the end of the time-base, and R_g = the input resistance of the amplifier, which is continually parallel to C_t.

It is seen that for $R_g \geqq R_t$ the velocity variation D does not exceed twice the ratio E_c/E_0. If for E_0 we use the voltage with which the amplifiers are fed (the value of which has been deduced above as 675 V) then with E_c = 20 V the velocity variation is limited to less than 6%, which is not found to be at all troublesome in practice.

As remarked some way back, the function of S in fig. 8 is performed by a valve. This is a pentode of the type EF 50 (see *fig. 9a*). It is brought into a squegging condition [5]), that is to say it is caused to oscillate during a short period when the negative grid voltage induced in the capacitor C_t is rapidly rising from about —2 to —20V (AB in fig. 9*b*); when the latter value is reached the slope has become so small as to stop the oscillation. A source with high voltage (675 V) supplies an opposite charge *via* the resistance R_t, causing the grid voltage to drop again to —2V, when the oscillation begins anew. The relaxation time T (fig. 9*b*) can be adjusted within wide limits by varying C_t and R_t; in the oscillograph GM 3159 the corresponding

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Fig. 10. External view of the cathode-ray oscillograph GM 3159. On either side of the screen, at the top, are the controls for brightness and sharpness of the light spot, and below those the controls for horizontal and vertical picture amplitude (resistor R_p of fig. 7). In the middle row from left to right: the switch S of fig. 1*b*, the coarse and the fine frequency regulators for the time-base voltage. The two controls at the bottom regulate the input potentiometers of the amplifiers. At the very bottom on the left and right are the plug sockets of the inputs *II* and *I* (fig. 1*b*); in the middle is the socket from which the saw-tooth voltage can be taken off for other measurements (*e.g.* of amplifiers). A cap can be fitted over the front panel to protect the screen and controls during transport.

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[5]) See, *e.g.* J. Van Slooten. The working of triode oscillators with grid condenser and grid resistance, Philips Techn. R., 7, 40 — 45, 1942, and Stability and instability of triode oscillators, Philips Techn. R., 7, 171 — 177, 1942.

frequency is variable between 10 and 150×10^3 c/s. If R_t and C_t were connected directly in parallel the voltage on C_t would follow a pronounced curve BC, but with the arrangement of fig. 9*a*, where a source of high voltage is connected in series with R_t, a practically straight line is obtained (fig. 9*b*).

In the amplifier A_h the saw-tooth voltage from C_t is amplified sufficiently to give a deflection across the whole width of the screen; this deflection can be regulated with the potentiometer Z_4 (fig. 1*b*).

Furthermore, the saw-tooth voltage is carried to a separate terminal so that it can be used for other purposes outside the oscillograph, *e.g.* for measuring amplifiers [6]), without any need for a separate signal generator.

Since the valve only takes up anode current during the short interval of oscillation, negative voltage impulses arise at the end B (fig.9*a*) of the resistance introduced in the anode circuit. By conducting these impulses to the control grid of the cathode-ray tube they can be used for suppression of the retrace of the beam. This often makes the picture clearer, but a small part of the oscillogram is then lost, and if this cannot be dispensed with it is necessary to switch off the beam retrace suppression, which can be done quite easily.

Construction of the apparatus

In its outward appearance the oscillograph GM 3159 (*fig. 10*) does not differ essentially from its

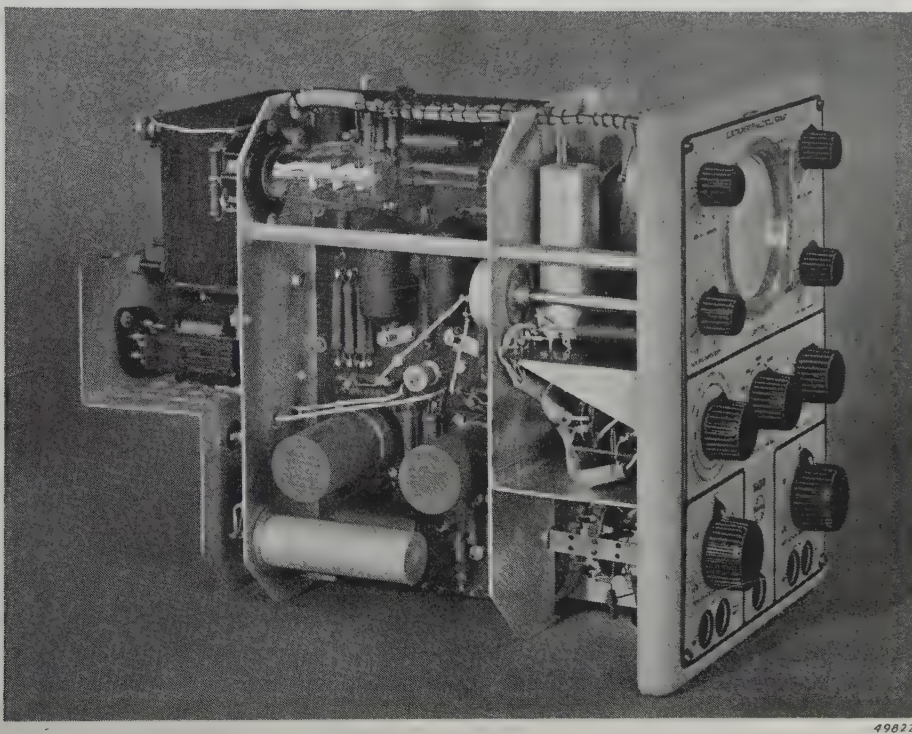

Fig. 11. An internal view of the oscillograph GM 3159. The compartment on the left contains the supply unit, the one in the middle the two amplifiers. The empty space on the left can be reached through a trap in the back of the casing and can be used for storing away the flexes.

The moment at which the slope again becomes large enough to start the pentode oscillating again can be controlled by applying an additional alternating voltage to the control grid. In this way only a small voltage suffices to synchronise the frequency of the time-base voltage with that of the extra voltage referred to.

[6]) The use, for such purposes, of voltages whose curves deviate strongly from a sine is described by J. Haantjes in: The judging of an amplifier by means of the jump characteristic, Philips Techn. R., 6, 193 — 201, 1942, which article deals with the use of a block-shaped voltage.

predecessors. There is more to be said about its internal construction, in particular about an improved magnetic screening and a new technique of assembly.

When a cathode-ray oscillograph is used in the vicinity of a strong magnetic field — for instance near transformers, electromotors and the like — that field is apt to cause troublesome deflections of the electron beam, unless the cathode-ray tube is adequately screened off against magnetic influences. That is why it is usual to insulate the tube

in a cylinder that has good magnetic conducting properties. This effect is expressed as the screening factor, which is defined as the ratio of the magnetic field strength outside the cylinder to that inside it. The thicker the wall of the cylinder and the higher the permeability of the material of which it is made, the greater is the screening factor. By using an alloy of very high permeability for the cylinder in the new oscillograph the screening factor has been raised from 12 to 500, whilst at the same time the weight of the cylinder has been reduced from 600 to 130 grammes. Thanks to the improvement in the magnetic screening the new oscillograph can be used where there are fairly strong magnetic stray fields.

To carry off the heat generated in the oscillograph horizontal partitions tending to obstruct the natural flow of air have been avoided wherever possible. The inside of the oscillograph is divided into three compartments by vertical metal partitions (*fig.11*) acting as screens between the component parts liable to influence each other. In the middle compartment are the two amplifiers placed back to back, each mounted on an insulating panel (*fig. 12*). Pressed into these panels are brass pins, to which the electrical parts are soldered at one end and the the wiring at the other, so that the wiring can be kept very short and at the same time strongly fixed, as are also the electrical parts, thus precluding troublesome capacity variations due to shifting about. The advantage of this method from the manufacturing point of view is that the units can be pre-mounted and tested before being built into the casing (see fig. 12).

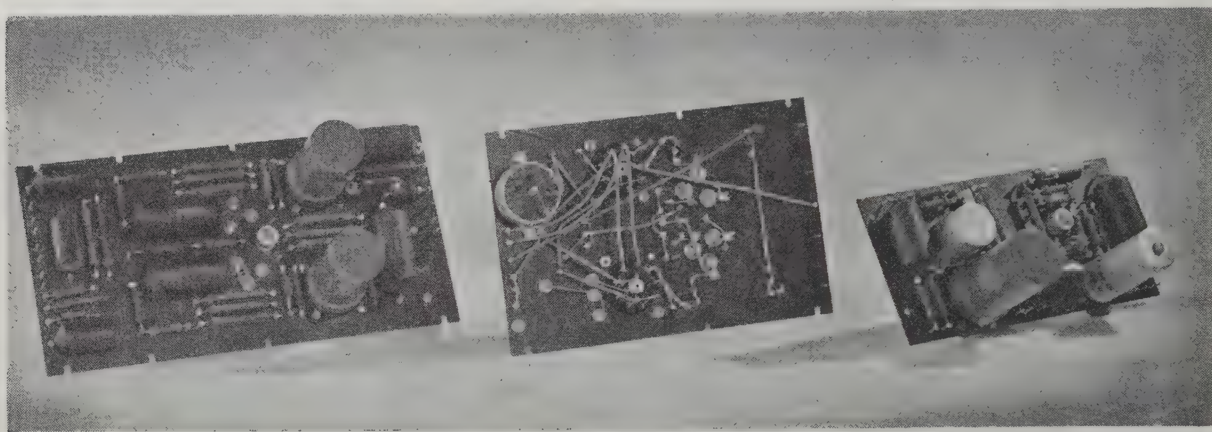

Fig. 12. Units mounted on insulating panels: on the left one of the push-pull amplifiers (rear view), in the middle the other amplifier (rear view), on the right the generator for the time-base voltage. (The two amplifier panels are not equal in size because on one of them some other parts are mounted which belong to the supply part.)

Finally it is to be mentioned that the dimensions of this oscillograph are 21 × 27 × 37 cm and that its weight is 13 kg. Compared with the GM 3152 for instance this means a saving of about 75% in volume and over 30% in weight, so that the new oscillograph gains much in handiness.

TESTING FOR NYCTALOPIA (NIGHT-BLINDNESS)

by W. S. FREDERIK.

612.845.6-073

For certain occupations or jobs inadequate adaptation for the dark (night-blindness) may be awkward. In some cases, for instance where it means that the person affected by nyctalopia has to be exempted from night work, the possibility of simulation has to be taken into account. When such a situation arose at Philips a simple method was developed by the Medical Department of this company for testing persons for night-blindness with no possibility of simulation. With this method, which has yielded good results in practice, during the adaptation to the dark the person being tested has to look at a specially composed letter card and read words from it which differ according to the state of adaptation.

Under favourable conditions the human eye is able to observe levels of brightness as low as 0.000 003 candle/m^2, (1 c/m^2 = 0.0929 c/sq.ft) while on the side of high brightness vision is only restricted by the limit of pain, which lies at 200 000 candles/m^2. For covering this extremely wide range of brightness the retina contains two kinds of light-sensitive elements: the cones, which act at high levels of brightness such as occur in daylight, and the rods, which gradually take over this visual function when the brightness of the field of vision falls below about 3 candes/m^2 (the level at which motorists usually switch on their headlights).

The light-sensitive substance contained in the rods is called rhodopsin or visual purple, which is composed of protein and vitamin A. The cones are assumed to contain three different light-sensitive substances, but it has not yet been found possible to determine them. It is further assumed that these light-sensitive substances are continually being formed as long as the eye can see, while at the same time they are destroyed by the light striking the eye. Between this formation and destruction of the light-sensitive substances an equilibrium is supposed to be established which determines their concentration, there being more light-sensitive substance present according as the brightness is lower, because the less light that strikes the eye the more slowly the substance is destroyed. In this way the sensitivity of the eye adapts itself to the level of brightness.

As regards the still unknown light-sensitive substances in the cones the mechanism sketched above is of course purely hypothetical. For the visual purple of the rods, however, experiments would appear to confirm that this is what actually takes place. The taking over of the function of vision by the rods, mentioned above, can now be explained simply as follows: whereas at a brightness higher than about 3 c/m^2 the concentration of visual purple is practically nil owing to its rapid decomposition, at lower levels of brightness the concentration gradually increases [1]).

The formation of the visual purple takes some time. This can easily be observed when, coming out of a brilliantly lighted room, one steps outside on a dark night: it takes several minutes before one can see well enough in the dark. The eyes do not become completely adapted to the dark until half an hour or more later, though as a rule the increase in light-sensitivity is greatest during the first 10 minutes, after which the increase is only relatively slight.

This adaptation to the dark does not proceed in the same way for all persons. When a large number of persons are tested the light-sensitivity of some of them is found to increase slower than normal though ultimately reaching a normal value, whereas with others the normal light-sensitivity is not reached even after a long time of adaptation. Such an aberration in the latter group, when the ultimate light-sensitivity remains below a certain limit, is called night-blindness (nyctalopia). In a number of cases this defect is found to be caused by a deficiency of vitamin A, which is understandable after what has been said above about the composition of visual purple (rhodopsin).

Persons with such defective adaptation have difficulties in perception in the dark, as in a poorly lighted street at night. There are several occupations for which such people are therefore unsuited, for instance as chauffeur and in certain positions on railways, in shipping and aviation and in the police. The testing of applicants for such positions should therefore include a test for night-blindness. The usual methods are practically all based on the

[1]) Why the cones, which according to our primitive conception should then contain a good quantity of light-sensitive substance, gradually cease to function just at these levels of brightness is not explained. It may be ascribed to the existence of an absolute threshold for the light-sensitivity of those elements lying in the range of brightness between about 0.03 and 3 c/m^2.

same principle: after some time in a brightly lighted room the examinee is taken into a very poorly lighted room where he has to recognize certain objects within a given time.

Provided the examinee is desirous of passing the test successfully there is not much to be said against such a test, but it may well happen that he desires to be rejected. When, for example, nyctalopia necessitates exemption from night duty, the examinee may try to simulate night-blindness and if tested on the above lines need only maintain that he cannot see any of the objects he is asked to recognize. It is then not easy to expose such a simulation and it is impossible to determine his true degree of adaptation to the dark.

A case occurred at Philips where account had to be taken of the possibility of night-blindness among a group of employees, and also of the possibility of simulation. When it appeared that no simple method was known which precluded simulation, the Medical Department of Philips devised a simple apparatus which meets this problem and has proved satisfactory in practice.

The principle of this apparatus is shown diagrammatically in *fig. 1*. A letter card, which will be described later, is placed in a light-proof box and illuminated by a small incandescent lamp *via* a diffusely reflecting screen, with a certain low luminous intensity which can by varied by means of an adjustable diaphragm placed in front of the lamp. After the person being tested has been kept for 10 minutes under standardized conditions to allow his eyes to get adapted to a certain high level of brightness, the room is completely darkened and he is made to look through a slit in the cabinet at the letter card at set times, say at intervals of 1 minute.

The letter card is shown in *fig. 2*. It bears the word BUURT on a black background. Each letter consists of different parts painted in tints of grey with different reflection factors. The letters are divided into parts in such a way that when the darkest part (the part with the smallest reflection factor)

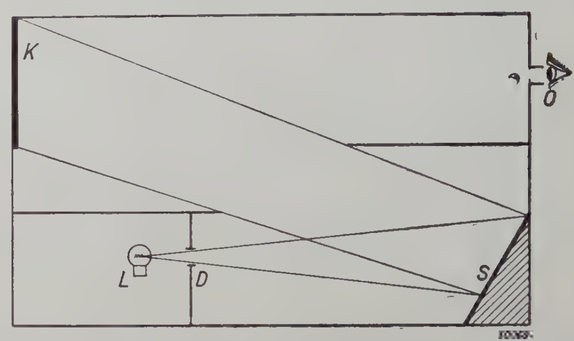

Fig. 1. Apparatus for testing night-blindness. The test person looks through the slit O in a light-proof box at a letter card placed at K. This is illuminated by one or more lamps L *via* the adjustable diaphragm D and the diffusely reflecting screen S. The horizontal partitions prevent any direct light from D falling upon the eye of the observer.

is omitted a different letter results, and upon omitting the darkest part of that in turn yet another letter is formed. For example, from the U an L is formed, and from the L an I. Taking the painted word as whole and successively omitting the darkest of the five tints we read in turn the following words: BUURT - BUUR - BULT - BUI - EL,

Fig. 2. Letter card used for the text. The letters, painted on a black background, are composed of five different shades of grey in such a way that upon successive omission of the darkest shades a different word results. The better the adaptation of the eye, the darker the shade that can just be observed, and thus the more complete the word that can be read. With progressing adaptation, therefore, the subject reads successively the words, EL - BUI - BULT - BUUR - BUURT.

which are all words commonly occurring in Dutch.

The intensity of illumination of the letter card is so chosen that a fully adapted normal test person can read the whole word BUURT. When he first looks through the slit, however, he will not, as a rule, see anything at all, because his eyes have just been adapted to a rather high level of brightness, thus possessing a low sensitivity to light. After a while his sensitivity has risen so far that he can see the brightest tint on the letter card and thus perceive the word EL. A little later his vision is sufficiently adapted to be able to read the word BUI, and so on. A remarkable feature about this is that in a certain state of adaptation upon a brief glance at the letter card only one word is perceived, and thus in the case last mentioned no need is felt to choose between BUI and EL. The reason for this is that at the low level of brightness of the letter card the contrast sensitivity of the human eye (*i.e.* the power of observing small differences in brightness) is much lower than in daylight, and in the five shades of grey used on the card the contrast between two successive shades is made so small (ratio of the coefficients of reflection 1 : 1.7) that it passes practically unnoticed at the low brightness mentioned, especially when only a brief glance is taken. (The series of words are built up in such a way that two adjacent parts of a letter always differ by one stage in reflection factor.) As a result, test persons who are unacquainted with the structure of the letter card do not immediately notice how the different words are formed from each other [2]).

The further procedure is as follows. Each time the subject looks through the slit of the instrument he is asked what word he sees. The numbers 1 to 5 are assigned to the five stages of sensitivity of the eye corresponding to the ability to read the five different words. The sensitivity value for the word EL is thus 1, that for BUI 2 and so on. When the sensitivity values found from the test are plotted as a function of the time, a curve is obtained for each subject representing the progress of his adaptation. Several of such curves are drawn in *fig. 3.*

Experiments were undertaken to ascertain the adaptation curves with a given letter card and a given intensity of illumination for normal persons and for those affected with night-blindness. "Normally adapting" persons were taken to be those who after 10 minutes adaptation could place themselves without difficulty in a dark street (a not very precise definition, but one appropriate to the case). The curves for night-blind people are found to be much flatter than those for normal persons.

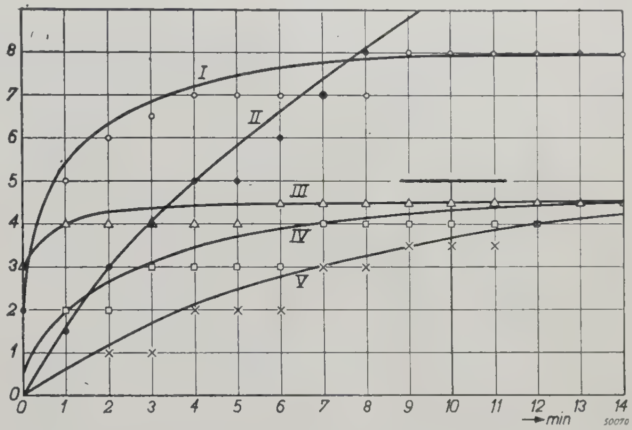

Fig. 3. Progress of adaptation to the dark for five different test persons. The values from 1 to 5 are assigned to the eye sensitivity corresponding to the ability to read the five successive words of the letter card. The sensitivity value is plotted as a function of the time for adaptation. The continuation of the curves above the value 5 was obtained as described in the text.
The three flat curves (*III*, *IV* and *V*) which at 10 minutes on the abscissa still lie below the limit indicated (sensitivity 5) represent three cases of night-blindness. There are large individual differences (as in fact also in the "normal" cases *I* and *II*). In the case of the subject *III* there is a very rapid initial adaptation, but considering the shape of the curve it is improbable that the eye sensitivity will ever rise above the value 5. On the other hand the test person *V* belongs to the group of people whose adaptation takes place very slowly but perhaps in time finally reaches a satisfactory sensitivity.

On the basis of the tests described we have taken as criterion for the existence of night-blindness that after 10 minutes the sensitivity of the eye has not yet reached the value 5. In fig. 3 three examples of this can be seen.

If desired, the progress of adaptation can be followed still farther, with the same apparatus, than to the increase of sensitivity corresponding to the value 5. When the sensitivity 5 has been reached (thus when the word BUURT has been read), the intensity of illumination of the letter card is reduced so that only the word EL can be seen. That word is then given the sensitivity value 5, the numbers 6, 7 etc. being assigned to the higher values of sensitivity reached upon further adaptation and causing the subject to read successively again the words BUI, BULT, etc. Where the curves in fig. 3 extend above the ordinate

[2]) For those who would like to make the test themselves with the letter card reproduced here, in order to convince themselves of the succesive appearance of the five words and of the fact that the contrasts between the parts of the letters are scarcely noticeable, it must be noted that the card has to be illuminated with about 0.0005 lux. This corresponds, for example, to the level of illumination on a clear, moonless, starry night. If the level of illumination is very much lower there is a chance that the whole word can never be seen, while if it is much higher the contrasts between the parts of the letters become too noticeable.

5 they have been determined in this way [3]).

Conversely, at every state of adaptation the complete word BUURT can immediately be made legible — also for night-blind persons — by increasing the intensity of illumination on the letter card to a certain level. If, for example, the subject was so far adapted that he could read the word BUI, the increase in sensitivity which would then be necessary for him to be able to see the three darkest shades on the card and thus to read the word BUURT becomes unnecessary, because at the higher illumination intensity these three shades become so much brighter. If a subject should then maintain that he can only read the word BUI, it is certainly a case of simulation. Such a case, however, has not yet occurred in practice, since with the method described here the subjects are quite unable to figure out how they can impress the examining doctor with the suggestion of night-blindness.

In conclusion we have to mention some details in the application of the method. Since at low levels of brightness visual acuity is very much reduced, the letters must be made fairly large. In our apparatus the word BUURT covered an area of 10 × 50 cm, while it was viewed from a distance of 40 cm. The variation required in the intensity of illumination of the letter card was obtained by using a number of small lamps as light source (instead of one) and/or changing the opening of the diaphragm (*D* in fig. 1). The more obvious method of using a sliding resistance in series with the lamp was expressly not employed because then when the light is reduced its colour is shifted towards the red, and as the eye sensitivity depends closely on the colour of the light this would cause errors in the estimation of the state of adaptation.

A small error, of little consequence for our purpose, may occur due to the fact that the "black" background of the letter card reflected a small part of the incident light. This error can be avoided by constructing the instrument in such a way that the letter card is observed under transmitted light.

In that case the letter card is also somewhat easier to make: the letters are sawn out of a metal plate and their different parts covered with translucent paper in different numbers of layers.

There would be no fundamental difficulty in replacing the relative calibration of the apparatus with the arbitrary scale of sensitivity values from 1 to 5 by an absolute calibration. It would then be possible to obtain absolute data about the adaptation power of the persons tested. This, however, was outside the scope of our object.

[3]) By slightly varying the illumination intensity to a certain degree also intermediate stages of the eye sensitivity can be measured, thus values of 1 1/2, 2 1/2, etc. There are many such intermediate values in the curves of fig. 3.

APPLICATIONS OF LUMINESCENT SUBSTANCES

by F. A. KRÖGER.

535.376:661.4

Luminescent substances are used when rays which are invisible to the human eye are applied and it is desired to make them visible. Such invisible rays may be beams of electrons (in cathode-ray tubes for oscillographs, television and radar apparatus), X-rays, utra-violet rays (in gas-discharge lamps), or infra-red rays. Here it is discussed what luminescent substances are most suitable for each of these cases.

Introduction

In technology it is often required to convert rays which are invisible to the human eye into visible rays. The originally invisible rays may be of a widely different nature. One may have to do with electro-magnetic waves differing considerably in length, or with very rapid electrons.

In the case of cathode-ray tubes, which are mainly applied in oscillographs, television sets and radar installations, it is a beam of electrons that has to be made visible. Medical practitioners meet the same problem in the screening of their patients with X-rays. The conversion of ultra-violet rays into visible light is applied in modern gas-discharge lamps. Finally there is to be mentioned the conversion of infra-red into visible rays, as was particularly applied during the last war.

It is not always that the ultimate object is to obtain visible light. Sometimes it is required to convert some irradiation or other into, for instance, ultra-violet of a suitable wavelength. This is the case, for instance, in irradiation lamps emitting ultra-violet of a certain wavelength which has a specific effect upon living organisms; applications of this are to be found, *inter alia*, in anti-rachitis and germicide lamps and so-called sun-tan lamps.

In all such cases as these use is made of substances which have the property of being able to bring about the desired transformation, and as in most cases it is a matter of producing visible light they are called luminescent substances or luminophores.

The transformation in question is called luminescence, Two effects are to be distinguished. Fluorescence is a process that predominates during the radiation, being the remission of the energy first absorbed, and after the radiation has stopped this usually disappears within a short time 10^{-5}—10^{-1} sec.). Phosphorescence on the other hand is particularly of importance after the radiation has ceased; the time during which this phosphorescence persists differs considerably according to the prevailing conditions, especially of temperature, persistences of some hours or even days being possible.

This rather rough definition of the two effects suffices for the purpose of the present article. If we were to go more closely into the theory of the phenomena of luminescence it would be necessary to define them more precisely, having regard to the mechanism of the atomic processes brought about by the phenomena observed. This, however, has already been dealt with more than once in this journal. We would only recall here Stokes' rule, which says that the wavelength of fluorescence is generally longer than that of the primarily absorbed exciting radiation [1]).

The luminescent substances used vary from one case to another. In this article a survey will be given of their most important applications and of the substances that can be used in the present stage of developments.

The conditions which these substances have to satisfy can be placed, broadly speaking, in three groups. In the first group we have those requirements that are related to the mechanism of transformation; the incident radiation has to be suitably absorbed, whilst the energy absorbed must not be converted into heat but into the desired luminescent radiation. To the second group belong those conditions that are determined by the properties to be expected of the fluorescent radiation excited, such as its spectral distribution and duration of persistence. Thirdly, the fluorescent substances, which, with a few exceptions, are obtained in powder form, must be capable of being applied in thin even layers; this depends upon the absolute as well as the relative size of the particles, whilst it is also necessary that the substances should not undergo any chemical change during manufacture (*e.g.* due to the use of adhesives).

Several of these points will be considered in more detail when dealing with particular cases, where it will also be investigated in how far the

[1]) For a closer study of the relation between absorption, irradiation and fluorescence see the articles by W. de Groot, Philips Techn. R., **3**, 125-132, 1938, J. H. Gisolf and W. de Groot, Philips Techn. R., **3**, 241-247, 1938 and F. A. Kröger, Philips Techn. R., **6**, 353-362, 1941.

development of luminophores has progressed to be able to satisfy these requirements.

Luminescent substances for cathode-ray tubes

Cathode-ray tubes are used for several purposes, the foremost being:
1) oscillographs,
2) television receivers,
3) radar installations.

Oscillographs

There are various forms of oscillograph tubes according to the purpose for which they are intended. For visual use a green fluorescence is desired, the persistence required being in some cases short and in others long. Short-persistent green is obtained with the aid of ZnS-Cu-Ni or $(Zn,Mn)_2$ Sio_4; with the former the luminescence arises from the traces of copper taken up in the crystal structure of ZnS. Nickel causes the short after-glow. Since the position of Cu and Ni in the lattice is uncertain, this system is indicated by writing ZnS-Cu-Ni; in the second case we have a mixed crystal, the manganese replacing the zinc; this is indicated by writing (Zn,Mn). Long-persistent green is obtained with ZnS-Cu or $(Zn,Mn)_2SiO_4$-As. ZnS-Cu is known to give a much longer persistence under the action of long-wave ultra-violet or blue than under the action of cathode-ray electrons. This makes it possible to extend considerably the duration of the after-glow by introducing a second luminescent substance in which cathode rays induce a violet light, which in turn brings about the green fluorescence and after-glow (the phosphorescence). The same applies for yellow luminescent (Zn,Cd)S-Cu, also under the action of blue light. The most favourable type is a double screen consisting of a yellow fluorescing layer (Zn,Cd)S-Cu on the glass and on top of that a second layer of blue fluorescing ZnS-Ag,$CaWO_4$, $Zn_2(Si,Ti)O_4$ or (Ca,Mg) (SiO_3-Ti).

If photographic recording is desired then a blue fluorescing screen is of advantage, and in that case a single screen with one of the last mentioned substances is sufficient.

Television receivers

In television receivers an electric signal is transformed into a visual picture by means of a cathode-ray tube. This picture may be formed on the screen of the tube itself (direct vision) or it may be projected by a system of lenses or mirrors onto a transparent screen on a magnified scale (projection television).

We have to differentiate between black and white and colour television.

For black-and-white television the fluorescent substances forming the screen have to emit a reasonably white light under the action of the cathode rays. This white colour must as far as possible be independent of the intensity of the cathode ray. Furthermore, the luminescent substances must not leave an after-glow, because otherwise rapidly moving objects would leave troublesome smudges of light.

The white colour is best obtained with a mixture of two substances, one emitting blue light and the other yellow. This is shown graphically in *fig.1* by

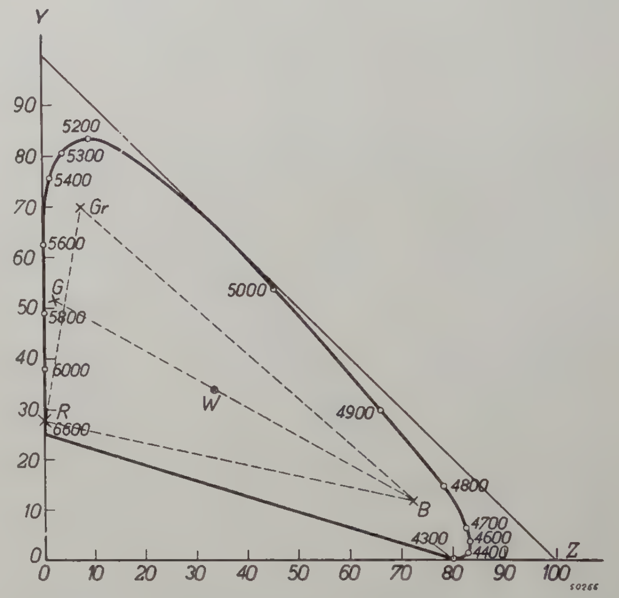

Fig. 1. In this colour triangle the colour point is plotted of the emission of a blue (*B*) and a yellow (*G*) luminescent substance. When two colours are mixed a new colour is formed, which is represented by a point on the line connecting the colour points of those two colours. White (*W*) lies on the line connecting blue and yellow. Further it is clear that white can also be obtained from the addition of a red, a green and a blue colour (*R*, *Gr* and *B*).

means of a colour triangle. For yellow (Zn,Cd)S-Ag, Zn(S,Se)-Ag and $(Zn,Be,Mn)_2SiO_4$ are used, and for blue ZnS-Ag, $Zn_2(Si,Ti)O_4$ and (Ca,Mg) $(Si,Ti)O_3$, none of which substances leaves any after-glow as to be troublesome.

Where low voltages are applied, as in direct-viewing tubes (*e.g.* 5 kV), the sulphides are to be preferred on account of their high intensity of radiation. In the case of higher voltages as used in projection tubes (*e.g.* 25 kV) the sulphides and the silicates are about equal in their intensities of radiation; in this article we shall not go into the question which of these two is to be preferred in the long run.

With some mixtures applied in practice small

variations in colour occur between parts of different brilliancy, due to the intensity of fluorescence of the components not depending in exactly the same degree upon the intensity of the electron beam. In the first place this arises from a divergence from the linear relation between those two quantities yielding the so-called current saturation. In the case of the sulphides, moreover, there may be a second effect: the emission from these substances consists sometimes of two bands lying in different parts of the spectrum, the one with the shorter wavelength increasing slightly at the cost of the other when the radiation density is increased.

For colour television there are various types of receivers. One familiar type is that commonly used when in the transmitter a quickly rotating disc having three sectors (red, green and blue) is employed, and in the receiver three filters, one for each of these primary colours. In that case not only is the fluorescence of the screen required to give a white colour but at the same time that white has to be of such a composition as to permit all possible colours to be obtained from it with the the aid of filters. This can be approximated fairly well by making up the white with the help of three fluorescent substances emitting light in the red, green and blue (see fig. 1). For blue we may again use ZnS-Ag, $Zn_2(Si,Ti)O_4$ or $(Ca,Mg)(Si,Ti)O_3$, for green ZnS-Cu-Ni or $(Zn,Mn)_2SiO_4$ and for red $(Zn,Mn)_3P_2O_8$, $(Ca,Mn)_3P_2O_8$, $(Zn,Be,Mn)_2SiO_4$ or the recently developed $Ca_2P_2O_7$-Bi.

Radar installations

It is well known that the name radar is an abbreviation for radio detection and ranging, which was highly developed during the last war. Short, high-frequency, radio impulses are broadcast by a transmitter, and their reflection back from metal objects in the air went a long way to detecting aircraft. Radar has also proved to be a valuable asset for the navigation of aircraft and ships. These are only two examples, for there are many applications of radar.

In a radar receiver is a cathode-ray tube with its screen coated with a fluorescent substance, on which the signal received is made visible. In the simplest forms of radar these fluorescent screens do not have to answer any very special requirements, so that the normal substances can be used as mentioned above when dealing with oscillograph tubes.

For the more complex forms, such as the plan-position-indicator (P.P.I.), it is a different matter. This is an instrument which - when used from the ground - indicates the position of aircraft in its surroundings, or inversely, when used from an airplane gives a picture of the landscape below. An electron beam emitted from a cathode-ray tube passes fan-like across the screen, being synchronised with the rotating antenna which broadcasts the signals and picks them up again. The movement of the beam over the screen is illustrated in *fig. 2*. The period of the rotation is from 1 to 6

Fig. 2. A cathode-ray beam causes a narrow linear part of the screen of the plan-position-indicator to light up. This ray travels round the screen in about 1 second while the cathode-ray beam moves up and down that ray at a high velocity.

seconds. If persistent fluorescent substances were not used only the rotating line would be observed, but with an after-glow on the screen the field continues to yield light after the line has passed on and gives a picture corresponding to the degrees of intensity of the cathode ray at the various points on the screen. It is therefore solely due to the after-glow that a picture is obtained over the whole screen.

For the screen of the P.P.I. the best results are to be obtained with a substance which is strongly persistent exactly during the period of rotation, say 1 second, and after that emits no light at all. If the after-glow is shorter then the entire picture can never be illuminated, whilst if it is longer there will be an overlapping of the pictures in situations of one-second intervals, so that moving objects become blurred. Hitherto it has not been possible to comply with this requirement of 1 second constant, strong after-glow and then extinction. An acceptable compromise, however, has been reached, as illustrated in *fig.3*, where the time is plotted on the x-axis and the intensity of the luminescence on the y-axis; the broken line ABC represents the ideal intensity change and the curve the approximation so far reached. Since the fluorescence under the action of the ray is much stronger than the phosphorescence there is a danger that owing to blinding nothing of the after-glow will be seen. Consequently it is necessary that the ratio of fluorescence to phosphorescence should be as small as possible.

In practice a double screen as desribed above for oscillograph tubes gives useful results. Provision is made in the first place for a strong phosphorescence. Since the fluorescence is mainly in the blue and the phosphorescence exclusively in the yellow, by using a filter which absorbs blue and allows yellow to pass through it is possible to suppress the intensity of fluorescence while maintaining the phosphorescence, By this means the ratio of fluorescence to phosphorescence can be appreciably reduced.

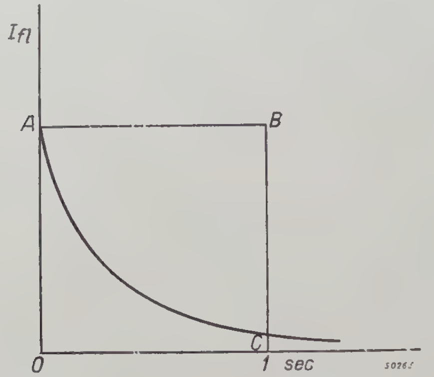

Fig. 3. Reduction in the intensity of fluorescence in a plan-position-indicator after the cathode-ray beam has passed. On the x-axis is the time and on the y-axis the intensity of the fluorescence. The broken line ABC represents the ideal intensity change and the curve the approximation hitherto reached.

Single screens of $(Zn,Mg,Mn)F_2$ have been suggested, but these have proved to be unsuitable on account of their chemical instability and high ratio of fluorescence to phosphorescence.

Luminescent substances in Roentgenology

Since X-rays have a great power of penetration only a small part is absorbed by the fluorescent screens used in X-ray apparatus. However, the larger the fraction absorbed, the more energy can be converted into visible light. Therefore the first requirement to be met by luminescent substances for X-ray screens is that they should have the largest possible absorption coefficient for X-rays. This power of absorbing X-rays depends directly upon the number of electrons contained in the ions that go to make up the substance. Consequently we have to use fluorescent substances consisting for a large part of heavy ions. This is the reason why such a substance as barium-platinum-cyanide, which is otherwise of little importance as regards fluorescence, has continued to be used such a long time for X-ray screens. Further, the heavy substances $CdWO_4$, $CaWO_4$ and the recently developed $(Ba,Pb)SO_4$ and $Ba(F,Ce)_2$ are used. Of course another factor of great importance is the yield of visible light to be obtained from the conversion of the energy absorbed. Since the zinc and zinc-cadmium sulphides are favourable in this respect also these substances can be used to advantage for X-ray screens notwithstanding their relatively low power of absorption.

With these fluorescent screens long after-glow must always be avoided. If tungstates are used they can be suitably prepared so as not to cause any troublesome phosphorescence. In the case of sulphides, which under the action of X-rays glow for too long a time, the same result is obtained by incorporating extremely small quantities of an element like nickel or manganese (so-called killers) which specifically suppresses phosphorescence.

Finally it has to be considered whether the screen is to be used for visual observations or for photographic recording (with magnification). In the former case substances have to be chosen which give the optimum fluorescence with respect to the spectral sensitivity curve of the human eye *i.e.* those with a green to yellow fluorescence. In the other case account has to be taken of the properties of the photographic plate, and there substances with a particularly blue fluorescence are indicated. $BaPt(CN)_4$-aq, ZnS-Cu(Ni) and also the corresponding (Zn,Cd)S-Cu(Ni) are used as green or yellow fluorescing substances, whilst $(Ba,Pb)SO_4$ and $CaWO_4$ belong to the blue-fluorescing category. In between we have $CdWO_4$ with its bluish-green emission over a wide range.

Luminescent substances for gas-discharge lamps

Discharge in mercury vapour of low pressure

A discharge in mercury vapour of low pressure yields some visible light, but the greater part of the energy is emitted in the ultra-violet part of the spectrum, mainly on the wavelength of 2537 Å. Nevertheless, this discharge can be used for lighting purposes because it has been found possible to convert this emission into approximately white light[2]). This is done with the aid of a mixture of substances which absorb the ultra-violet radiation and each emit in a particular part of the visible spectrum. The substances used for this purpose are listed in *table I*.

Practically any colours desired can be obtained with mixtures of these substances. The last one listed is of particular importance, because with this alone a sufficiently white light can be obtained, though with small deficits in the green and the red.

[2]) See the articles in Philips Techn. R., 3, 272-278, 1938; 4, 342-350, 1939 and 6, 65-73, 1941

All these substances answer the requirement of being able to absorb the radiation to be converted while at the same time giving a high yield from the conversion of the energy absorbed. The yield varies from 80 to 95 quanta of fluorescent light per hundred quanta of ultra-violet.

Table I. Some luminescent substances used for mercury discharge lamps with low pressure. The last column gives the time taken for the fluoresence to drop to about one-third.

Luminescent substance	Colour of fluorescence	Dimming time
$CaWO_4$	blue	$\sim 10^{-5}$ sec
$MgWO_4$	bluish-green	,,
$(Zn,Mn)_2\,SiO_4$	green	$\sim 10^{-2}$ sec
$(Zn, Be, Mn)_2\,SiO_4$	yellow to orange	,,
$(Cd. Mn)_2\,B_2\,O_5$	orange-red	,,
$(Ca, Mn, Ce)_3\,P_2O_8$	red	,,
$(Ca, Mn, Sb)_5\,P_3\,O_{12}\,(Cl, F)$	blue	$\sim 10^{-4}$ sec
	yellow	$\sim 10^{-2}$ sec

Gas-discharge lamps normally work on alternating current, so that the intensity of the primary ultra-violet emission varies sinusoidally 50 times per second, which means that a dark interval occurs 100 times per second. Of course these dead moments occur also with an incandescent lamp connected to A.C. mains, but in such a lamp the slow cooling of the tungsten filament ensures that the light does not drop during these short intervals. When using luminescent substances the dark periods can be bridged over, in principle, by choosing substances which fluoresce for some time after the interruption of the excitation, so that the fluorescence starts to increase again before it is entirely extinguished; in other words, the ripple in the fluorescent light is smaller than in the ultra-violet emission of the discharge.

The duration of this after-glow differs as between one substance and another. With substances comprising manganese as the element responsible for the fluorescence the radiation drops to one-third in about 0.01 second, which is roughly sufficient for a reasonable smoothing out. For the green and red fluorescence this problem is therefore satisfactorily solved when using one of the last five substances of table I. The decay time of the blue and bluish-green fluorescing components hitherto used is much shorter (10^{-4}—10^{-5} sec), with the result that the lamps at present on the market, which emit white light during the live periods, fluoresce with an orange-coloured light during the dead periods. This is apt to have unpleasant consequences for anyone working under the light of these lamps: there is still some flickering, and with rapidly moving objects there is a certain amount of stroboscopic effect. This difficulty can be overcome, in principle, either by modifying the known substances so as to get a longer after-glow or by developing entirely new substances having a sufficiently long after-glow. The first problem can be solved by incorporating suitable foreign ions in the crystals so as to make the substances phosphorescent. As a new substance with a longer after-glow, a blue luminescent cadmium phosphate activated with lead has recently been mentioned by English investigators, but apparently it has not yet been used in practice.

The discharge tube with mercury of low pressure can be applied for various purposes other than for illumination, as for instance in light-printing processes and for medical, cosmetic and biological purposes.

These applications require violet or ultra-violet emissions of different wavelengths. In the light-printing process the range is from 3300 to 4300 Å. Radiations of a slightly shorter wavelength (3000-4000 Å) promote pigmentation of the human skin. For light-printing lamps as well as for sun-tan lamps $CaWO_4$, $(Ca,Ce)_3P_2O_8$ or $(La,Ce)_2S_3O_{12}$ can be used. Rachitis can be checked with a source of radiation between 2700 and 3000 Å, which promotes the formation of vitamin D in the skin; for this purpose $(La,Ce)F_3$ or $Ca_3P_2O_8$-Tl have been proposed as fluorescent substances. For the promotion of plant growth blue and red light is of importance, and for that purpose tubes can be used which are lined with $CaWO_4$ (blue) and/or $Cd_2B_2O_5$-Mn (orange-red). Finally it may be added that ultra-violet radiation of very short wavelength causes on the one hand erythema in the human skin while on the other hand it kills bacteria. The 2537 Å radiation from the discharge itself serves this purpose, without any need of conversion and thus not requiring any fluorescent substance; the wall of the tube, however, has to be made of a suitable material, because ordinary glass does not let these rays pass through.

A property that is of importance in luminescent substances and therefore desired for all the applications mentioned above is stability of the intensity of the radiation, also when the substance is exposed to the discharge for any length of time. This requirement is never fully satisfied, for after a time the emission always drops a little. The cause of this reduction in fluorescence is not quite clear. Probably it is an intricate effect in which both photochemical decomposition and

absorption of mercury play a part. Of the substances used tungstate is the most stable, whilst cadmium borate is the least stable. The other substances can be obtained in a fairly stable form by careful preparation.

Discharge in mercury vapour of high pressure

The high-pressure mercury discharge tube emits short-wave ultra-voilet (λ = 3200 Å) as well as long-wave ultra-violet (λ = 3650 Å) in addition to the rather large quantity of visible light (lines at 4047, 4358, 5461 and 5780 Å). With this irradiation the tube can be used directly as a source of light; but the colour of the light is of an unpleasant greenish tint, due to the very uneven distribution of the intensity over the spectrum, with light deficiencies particularly in the red and blue. As regards the red this deficiency has been successfully compensated by using the mercury discharge lamp in combination with an incandescent lamp, which has an excess of red [3]). This solution of the problem has the drawback, however, that all the ultra-violet emission is lost. A more efficient solution is to use fluorescent substances which convert the ultra-violet into the desired red and blue, which means to say that substances have to be used which can be excited by a radiation of a wave-length $\lambda < 3700$ Å; moreover, the fluorescence of these substances must not be affected by a rise in temperature.

If the fluorescent substance were to be applied direct on or in the discharge tube the rise in temperature would amount to about 400 °C. Since at such high temperatures most of the luminescent substances lose their power of fluorescence, it is desired to limit the elevation of temperature as far as possible. This can be achieved well enough by applying the fluorescent substance on the bulb enveloping the quartz discharge tube. Even so, in the case of a bulb 10 cm in diameter the temperature rise is still 100 - 150 °C, for a power of about 200 watts.

Table II gives a list of some red-fluorescing substances which can be excited with long-wave ultra-violet. This table also shows the temperature at which the intensity of the fluorescence has dropped to 80% of the maximum. In *fig. 4* graphs are given for some of these substances showing how the intensity of their fluorescence is governed by the temperature.

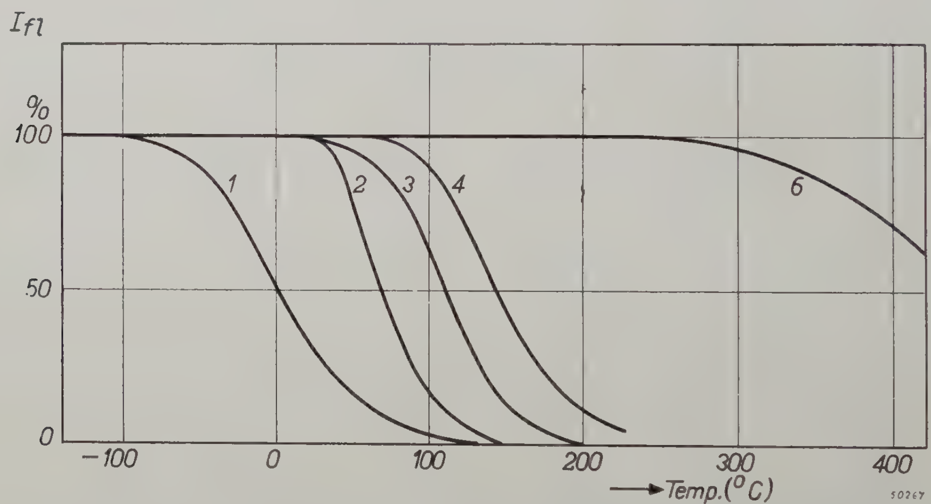

Fig. 4. Graphic representation of the manner in which the intensity of fluorescence in some luminescent substances varies with the temperature. The numbers beside the curves refer to the substances in table II.

Table II. Red fluorescing substances that can be activated with long-wave ultra-violet.

	Fluorescent substances	Temp. at which I_{fl} = 80% I_{max}
1	Cd (W,U) O_4	—35 °C
2	(Ca, Mg) 0.6 Al_2O_3-Mn^{4+}	45
3	$SrAl_2O_4$-Mn^{4+}	84
4	Mg_2TiO_4-Mn^{4+}	112
5	(Zn, Cd) S-Cu	200
6	$(Al, Cr)_2 O_3$	372

The first three of the substances listed in table II cannot be considered because their fluorescence is quenched at too low a temperature.

Of the others only (Zn,Cd)S-Cu has a sufficiently high maximum yield, and that is why this substance is used in practice. But then there is the

[3]) Philips Techn. R., 5, 353-359, 1940.

drawback that this yellow substance absorbs blue and violet, so that the light from the lamp gets a greenish tint.

Discharge lamps with rare gas

For illuminated advertisements discharge lamps are often used which are filled with a rare gas. When neon is employed the discharge itself gives a red light. The ultra-violet radiation of short wavelength contained in the emission spectrum of rare gases can be transformed into visible light with the aid of luminescent substances, the most important of which for this purpose are Zn_2SiO_4-Mn, $(Zn,Be)_2SiO_4$-Mn and $MgWO_4$.

Detection of infra-red

In the beginning of this article we mentioned Stokes' rule, which says that luminescent substances convert the absorbed electromagnetic energy into a radiation of longer wavelength. It therefore seems strange that these substances can be used for detecting infra-red rays, but that is indeed so.

The use of luminescent substances for detecting infra-red rays became of particular importance during the last war, though it had been known a long time already that some of them, possessing the property of being able to store a large quantity of energy, can be influenced by infra-red rays. The presence of infra-red radiation can therefore be detected with the aid of such substances. This can occur in two entirely different ways, because irradiation of an activated system with infra-red may have two opposite effects:

1) extinction of the phosphorescent light, and
2) accelerated emission of the stored energy (increased phosphorescence).

Several systems show the two effects to a different degree. Sometimes a system reacts in only one of these two ways, while in other cases both effects occur. Either of these effects can be used equally well for the detection of infra-red, and as a matter of fact substances have been prepared for both of them.

Any luminescent substances that can be considered suitable for this purpose must be capable of storing as large a quantity of energy as possible.

Substances used for the extinction effect must have a weak but persistent phosphorescence. As such ZnS-Cu-Mn has been used. When infra-red rays strike this substance a short flash of fluorescence is observed, but after that the phosphorence is completely quenched.

Substances used for the increased phosphorescence effect must have the least possible spontaneous phosphorescence, as otherwise the infra-red effect would be too little noticeable and, moreover, the store of energy would be soon exhausted.

In America and Germany, about the same time, substances were developed which after having once been irradiated retain the stored energy for months on end. These are Sr(S,Se)-(Sm,Eu) and Sr(S,Se)-(Sm,Ce). Also ZnS-Cu-Pb has favourable properties in this respect. To give an idea of the activity of these substances it may be noted that 0.1 mm^3 of such a substance viewed through a lens with a focal distance of 2.5 cm can produce for one hour a light of an intensity equal to 100 times the threshold value of the eye.

At the risk of superfluity we would once more point out that in any case the infra-red radiation only has its effect when the system has previously been irradiated, either with short-wave rays or with corpuscular rays. In case 2) it is not, therefore, a matter of visible light being excited by infra-red radiation. Thus the phenomena are by no means contradictory to Stokes' rule.

In conclusion we would mention in a few words other systems of infra-red detectors where use is likewise made of fluorescent substances [4]). Here the sensitive layer is a substance from which electrons are released by exposure to light. After having been accelerated these released electrons are concentrated on a fluorescent screen and made visible that way. For these systems the same luminescent substances can be used as described above for oscillograph tubes.

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[4]) G. Holst, J. H. de Boer, M. C. Teves and C. F. Veenemans, Physica 1, 297-305, 1934.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of the majority of these papers can be obtained on application to the Administration of the Research Laboratory, Kastanjelaan, Eindhoven, Netherlands. Those papers of which no reprints are available in sufficient number, are marked with an asterisk.

1729: J. L. Snoek: New developments in ferromagnetic materials; Elsevier publishing Company, Inc. New York, Amsterdam 1947, 136 pages, 52 fig.

This book is not a textbook on the subject but it gives a collection of publications on research work, carried out in 1940-1945. It is divided into three chapters dealing with the "statics" and "dynamics" of ferromagnetism and the development of magnetic materials respectively. The first chapter includes such topics as the general theory of hysteresis, hysteresis at low values of the induction, crystal anisotropy and magnetostriction in ternary systems, permeability and coercive force of cubic ferromagnetic oxides, effect of cold rolling on the alloys of Ni and Fe. The second chapter chiefly deals with the magnetic after effect and dis-accomodation in alpha iron as well as in ferromagnetic non-metals. Other topics referred to are: eddy current problems, magnetic skin-effect, large Barkhausen discontinuities. The third chapter gives extensive information on new magnetic ferrites developed by the author and co-workers ("ferroxcube" 1,2,3,4) and in addition gives some information on magnet steels.

1730: E. J. W. Verwey: Theory of the stability of lyophobic colloids (J. phys. and colloid Chem. **51**, 631-636, 1947.

The theory of the interaction of the double layers, surrounding colloidal particles in suspension in the presence of an electrolyte, has been reviewed in relation to the stability of lyophobic colloids. It is concluded that the interaction of the double layers must be associated with an increase of free energy, leading to a repulsion between the particles. The calculated repulsive potential for special cases has been combined with the van der Waals-London attractive potential calculated by Hamaker, to obtain curves of potential vs. distance. Predictions based on these curves appear to agree well with various experimental data. For example, the influence of electrolytic concentration and of the valencies of the ions on flocculation is satisfactorily explained in terms of the theory, although many complicated phenomena remain to be correlated with it.

1731: Th. P. J. Botden and F. A. Kröger Fluorescence of cadmium borates activated by manganese (Physica **13**, 216-224, 1947).

In the system CdO. B_2O_3 four compounds exist, each of which show fluorescence when activated by manganese. $Cd_2B_2O_5$-Mn is excited by $\lambda < 3200$ Å and cathode rays and than shows an orange luminescence, whereas CdB_2O_4, $Cd_2B_6O_{11}$ and $Cd_3B_2O_6$ show a green cathodo-luminescence only.

The luminescence of the $Cd_2B_2O_5$-$Mn_2B_2O_5$ phase has been studied quantitatively both as a function of the manganese content and as a function of the exciting radiation and temperature. It is shown that an ultra-violet emission appearing at low temperatures in some of the products cannot be responsible for the anomalous decrease of the red luminescence towards low temperatures.

1732: F. A. Kröger: Fluorescence of tungstates and molybdates (Nature **159**, 674, 1947).

A number of molybdates and tungstates which are non-luminescent at ordinary temperatures prove to show luminescense at low temperature. The temperature-quenching of the luminescence of a number of tungstates and molybdates in the interval —200 °C to + 200 C° is given in a graph.

1733: F. A. Kröger: Tetravalent manganese as an activator in luminescence (Nature **159**, 705, 1947).

In a number of systems, such as zinc aluminate, magnesium aluminate, α- and β-aluminium oxide and magnesium titanate, all activated with manganese, the luminescence is markedly different according as the products are prepared under oxidizing or reducing conditions. The reduced products (except the titanate) show a green cathodo-luminescence, which is due to divalent manganese. The oxidized products show a deep red luminescence upon excitation by cathode rays or ultra-violet (3650 Å). The valency of Mn in magnesium titanate was found by titration to be between 3 and 4. Analogy between the emission spectra of Mg_2TiO_4-Cr^{3+} and Mg_2TiO_4-Mn shows that Mn is present in the form Mn^{4+}.

1734: E. J. W. Verwey: Nieuwe onderzoekingen over de atoomrangschikking in spinellen in verband met hun physische eigenschappen (New investigations on the atomic arrangement in spinels in relation to their physical properties) (Chem. Weekblad **43**, 229-232, 1947).

For the contents of this paper the reader is referred to Philips Techn. Rev. **9**, 186-191 and 239-248, 1947.

1735: A. van der Ziel and A. Versnel: Total emission noise in diodes, Nature **159**, 640, 1947.

Measurements of the input damping $1/R$ and the equivalent saturated diode current I_e were carried out at 7.25 m wavelengths on a diode (cathode area 10 cm^2, anode-cathode distance 0.1 cm). Both quantities are approximately proportional to V_a^{-2}. The total emission may be described by assuming the "equivalent noise temperature" T_e of the conductance $1/R$ to be equal to the cathode temperature. It is expected that this result will hold for a very wide frequency range, because $1/R$ and I_e are both proportional to the square of the frequency.

1736: A. van der Ziel: Total emission damping in diodes, Nature **159**, 675, 1947.

Measurements of the "total emission damping", which is a transit-time effect due to space charge and occuring at ultra high frequencies,were carried out at 5.8 m wavelength on a diode (cathode area 10 cm^2, cathode-anode distance 0.1 cm). The conductive part $1/R$ and the reactive part $\omega\Delta C$ are plotted against V_a (heater voltage 6, 8, 10 and 12 V.) It is proved that $\omega\Delta C$ and $1/R$ are proportional to V_a^{-1} and V_a^{-2} respectively. It is to be expected that ΔC will scarcely depend on the frequency and that $1/R$ will be proportional to ω^2, except for the highest frequencies.

1737: J. L. Snoek: Gyromagnetic resonance in ferrites, Nature **160**, 90, 1947.

In polycrystalline magnetic ferrites of great homogeneity prepared by the author the tangent of the loss angle between B and H is found to rise at about 10 Mc/sec. from values less than 0.01 to values exceeding 1. At the same time the permeability goes down to very low values. The results are compared with the Landau and Lifshitz theory of gyromagnetic resonance expected to occur in a ferromagnetic dielectric if the frequency of the applied field equals the precession frequency of the spins around the direction of the internal field. (In Landau's model the specimen is assumed to be a single crystal and the applied field is at right angles to the crystal field). According to Landau

$$\frac{\chi_t \cdot f_h}{I_{\max}} = \frac{\sqrt{2}}{2\pi}\,\frac{e}{mc} = 4 \times 10^6 \text{ cycles/Oe.sec.}$$

(χ_t = transverse susceptibility, f_h = frequency for which the real part of the susceptibility is halved, $I_{\max}$ = saturation magnetisation) whereas for the polycrystalline sample this expression equals 1.75 10^6 cycles/Oe.sec.

The approximate agreement warrants the conclusion that the rapid decrease of the permeability in ferrites at high frequencies is probably due to gyromagnetic resonance around directions prescribed by the internal field.

1738: E. J. W. Verwey and E. L. Heilmann: Physical properties and cation arrangement of oxides with spinel structures. I. Cation arrangement in spinels, J. Chem. Phys. **15**, 174-180, 1947.

For the contents of this paper see the article by E. J. W. Verwey, P. W. Haayman and E. L. Heilmann, Philips Techn. Rev. **9**, 186-191, 1947 (No. 6).

1739: E. J. W. Verwey, P. W. Haayman and F. C. Romeyn: Physical properties and cation arrangement of oxides with spinel structure. II. Electronic conductivity, J. Chem. Phys. **15**, 181-187, 1947.

For the contents of this paper see the article by E. J. W. Verwey, P. W. Haayman and F. C. Romeyn, Philips Techn. Rev. **9**, 239, 1947 (No. 8).

1740: A. H. W. Aten: Activation of hafnium with neutrons, Science **105**, 386, 1947.

With slow neutrons acting on Hf a period of 20 sec. is found; with fast neutrons periods of 20 sec., 10 min. and 6 hours. As the stable Hf isotopes are 174, 176, 177, 178, 179 and 180 the second period is supposed to be due to Hf 175. The results are compared with those of Flammersfeld. The periods found are useful for the determination of Hf as a contamination of Zr whereas the long periods of Zr may be used for the determination of Zr as a contamination of Hf.

1741: J. A. Keverling Buisman, W. Stevens and J. van der Vliet: Investigations on Sterols. I. A new synthesis of 7-dehydrocholesterol (provitamin D), Rec. Trav. Chim. Pays Bas **66**, 83-92. 1947,

A new synthesis of 7-dehydro-cholesterol (provit-

amin D_3) from cholesterol is described, which gives a higher yield than the well-known Windaus synthesis. The synthesis is carried out via a 7-bromo cholesteryl ester, from which hydrogon bromide is eliminated to give an ester of 7-dehydro cholesterol.

1742: A. H. W. Aten: High energy ions in crystal lattices, Phys. Rev. **71**, 641-642, 1947.

The valency is determined of P^{32} ions formed by (n,p) and (n,α) reactions due to recoil in crystals containing S and Cl respectively. It is an open question whether the phosphate and phosphite ions are formed inside the lattice or whether they adopt their final state at the moment the crystal is dissolved.

1743: W. P. van den Blink: Note on the influence of the water content of an electrode-coating on the hydrogen content of weld metal, Welding J. Res. Supp. July 1947.

The question is discussed whether an increase in the moisture content of the coating of a welding electrode increases the hydrogen content of the weld metal. It is shown that both an increase and a lowering of the hydrogen content may result, dependent on the partical pressures of H_2O, CO, H_2 and CO_2 in the welding arc.

1744: K. W. de Langen: The manifold of physical quantities, Physica **13**, 349-352,1947.

In electrodynamics all operations are carried out in a manifold of quantities each element of which may be written in the form

$$a \text{ cm}^k \text{ g}^l \text{ sec}^m \text{el}^n$$

(el = electrostatic unit of charge). The numbers k, l, m, n determine the class of the quantity (dimension). The author advocates the use of quantity equations ("Grössengleichungen").

1745: J. H. F. Custers: The texture of copper wire drawn with backpull: Physica **13**, 366-378, 1947.

The preferred orientations of copper wire drawn in the normal way and with backpull respectively have been investigated. In the outer zones these orientations show distinct differences. In wire drawn with backpull the so-called conical fibre texture which predominates especially in the outer zones has developed less intensively than in wire drawn in the normal way. It is, however, still an open question whether properties like tensile strength are inproved in such a degree as to lead one to expect special advantages by the application of backpull.

1746: J. F. H. Custers: Note on the measurement of specular and diffuse photographic density, Photogr. J. Sect. B **87**, 59-63, 1947.

In measuring the density of photographic films, the smallest value or so-called diffuse density is measured when the measuring instrument catches the whole transmitted flux and the largest value or so-called specular density when only the flux transmitted normally to the layer is recorded.

The author has made some measurements in order to test a method recommended by Pitt (1938) for separating specular and diffuse density. He arrives at the conclusion that Pitts method can be used only for films or layers which scatter light according to Lambert's cosine law whereas it is of little value for all ordinary photographic films or plates because these show a scattering mechanism which obeys quite different laws.

1747: P. M. van Alphen and C. J. Dippel: New technical possibilities in the micro-reproduction and multiplication of documents. Rapports de la 17me conférence de la F.I.D. Berne, 25-30 août 1947.

An analysis is made of the possibilities and limitations in connection with the resolving power and optical conditions for recording a micro-picture and making it legible.

The contents of this paper cover partly the articles by C. J. Dippel and coworkers in Philips Techn. Rev. **9**, 65-72, 1947 (No. 3) and Philips Techn. Rev. **9**, 289, 1947 (No. 10).